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RESEARCH ON THE ATTERBERG LIMITS OF SOILS

By ARTHUR CASAGRANDE, Research Assistant, United States Bureau of Public Roads [1]

THIS report is a detailed account of research on Atterberg's liquid and plastic limits of soils, carried on by the Massachusetts Institute of Technology, the United States Bureau of Public Roads cooperating. Special attention is paid to the development of a mechanical device for the liquid limit test, the use of which has led to a clearer understanding of the physical significance of the liquid and plastic limit tests.

The procedures described in this report are those used in this investigation. They are not intended for routine testing in subgrade work. For this purpose simpler procedures published previously in PUBLIC ROADS have been adopted by the Bureau of Public Roads. The apparatus for making the liquid limit test mechanically, however, may prove advantageous for standardizing the test procedures used in the different subgrade soil laboratories. Additional investigation of the significance of the flow curve, the flow index, and the toughness index furnished by means of the liquid limit device offers an attractive field for research in soil physics.

The most conspicuous physical property of a clay is its plasticity. This property has, therefore, been studied extensively as a basis for distinguishing between clays and nonplastic soils and for classifying different clays according to the degree of their plasticity.

The method suggested about 20 years ago by A. Atterberg (1)[2] for measuring the relative plasticity of soils has been described at length in PUBLIC ROADS (2, 3, 4). It consists of tests for disclosing the upper and lower limits of the plastic state, or the so-called liquid and plastic limits. The numerical difference between these two values is the plasticity index.

How the limit tests, in conjunction with other simplified soil tests, disclose relationships which allow an approximate determination of those physical properties which influence the behavior of subgrades, has previously been reported in PUBLIC ROADS (6).

Further and more conclusive evidence of the relationship between the results of Atterberg's limit tests and the fundamental physical property, shearing resistance, is furnished by the investigations described in this report.[3]

The more exact requirements of research in soil physics and foundation design necessitated the development of the mechanical device which eliminates almost entirely the personal equation in the determination of the liquid limit. Prior to describing this apparatus, disclosing its application in soil investigations and discussing the significance of the results furnished by its use in special investigations, it seems desirable to introduce a digest of Atterberg's paper (1).

ATTERBERG'S ORIGINAL LIMITS OF THE PLASTICITY OF SOILS

The "limits of consistency" which Atterberg established in order to get a clearer conception of the range of water contents of a soil in the plastic state are as follows:

1. The upper limit of viscous flow, at which a mixture of clay and water flows as a fluid almost like water.

2. The lower limit of viscuous flow, the "liquid limit," at which two sections of a soil cake, placed in a cup (see fig. 1) barely touch but do not flow together under the impact of several sharp blows.[4]

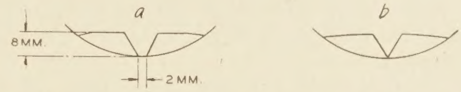

FIGURE 1.—DIAGRAM ILLUSTRATING LIQUID LIMIT TEST. FIGURE 1, *a* SHOWS WIDTH OF GROOVE AND HEIGHT OF SOIL PAT; 1, *b* SHOWS CLOSED GROOVE AFTER TEST

3. The "sticky limit," at which the clay loses its adhesive property and ceases to stick to other objects, such as the hands or a metal blade.[5]

4. The "cohesion limit" (Zusammenhaftbarkeitsgrenze), at which the grains cease to cohere to one another [5].

5. The lower limit of the plastic state, or the plastic limit, at which the soil crumbles when being rolled out into threads.

6. The lower limit of volume change or the shrinkage limit, at which further loss of moisture does not cause a loss in volume.

Atterberg considered that the amount of sand which can be added at the liquid limit without causing the soil to completely lose its plasticity is a measure of the plasticity of the soil. He found further, that the difference between the liquid and plastic limits, the plasticity index, represents a satisfactory measure of the degree of plasticity of the soil as indicated by the sand admixture.[6]

Consequently, he suggested that the difference in these limits, or the plastic range, expresses numerically the plasticity of a clay mixture and therefore may serve as a basis for classification.

PROCEDURES FOR DETERMINING THE PLASTIC AND SHRINKAGE LIMITS IN THIS INVESTIGATION

The procedure used in determining the plastic limit is essentially that previously described in PUBLIC ROADS (9). Except for the additional requirement [7] that the threads should be rolled out to a thickness of

[1] Mr. Casagrande has recently terminated his connection with the bureau and with the Massachusetts Institute of Technology and is now a lecturer at Harvard University.

[2] See bibliography at the end of this report. Numerals in parentheses refer to the articles listed in the bibliography.

[3] The significance of the Atterberg tests with respect to the ceramic industry is thoroughly discussed by Alfred B. Searle (5).

[4] There is no well-defined limit between the state of viscous flow and that of plastic flow. A valuable study on this subject is furnished by B. A. Keen and G. W. Scott Blair (7).

[5] The sticky and the cohesion limits are not discussed in this report. With respect to the former, however, it should be noted that "the sticky limit corresponds to the 'standard consistency' in the ceramic industry. Low sticky limit makes the working of the clay more difficult in agriculture, as well as in industry. The relative position of the sticky limit is increased by the addition of sand in large amounts, or organic matter in small amounts."

[6] The plasticity index, however, does not necessarily indicate the plasticity of ceramic materials as disclosed by the direct methods of measurements involving the three variables, force, shape, and time. See Searle (5), p. 272.

[7] This requirement was introduced by Professor Terzaghi (3, 8) who found that the water content at which threads will start to crumble is also dependent upon the diameter of the threads.

one-eighth of an inch (3 millimeters), this is Atterberg's original procedure. The procedure being used in the routine testing of subgrade soils at the Arlington, Va., laboratories for determining the shrinkage limit is described in the October 1931 issue of PUBLIC ROADS (9). Except in the preparation of the soil sample, the procedure used by the writer is similar to the Arlington procedure, calculating the shrinkage limit according to the "optional methods."

In the Arlington procedure the sample is molded from a paste consisting of dried soil powder mixed with water in amount slightly above the liquid limit.

In the writer's procedure the soil sample was kneaded into the shape of a disk slightly above the plastic limit, thus conforming more closely to the Atterberg definition. Dried compression test samples were used for the shrinkage limit determination.

The volume of the dried sample was determined by dividing the weight of the displaced mercury by its specific gravity.

The computation of the shrinkage limit according to the optional method as published in PUBLIC ROADS (9) makes use of the formula

$$S=\left(\frac{1}{R}-\frac{1}{G}\right)\times 100$$

in which

S = shrinkage limit

R = the apparent specific gravity of the dried soil cake

$=\frac{W_o}{V_o}$, the weight of the dried soil cake divided by its volume.

G = the true specific gravity of the soil particles.

The shrinkage limit of soil fragments dried in the undisturbed state may also be calculated by means of this formula.

MECHANICAL DEVICE FOR MAKING THE LIQUID LIMIT TEST

The liquid limit device designed to perform the liquid limit test mechanically in accordance with Atterberg's definition is illustrated by the photograph, Figure 2, and the drawing, Figure 3. It consists of a brass cup and carriage and a grooving tool.

Attached to the brass cup, C, is a handle, D, so shaped that it serves first as a hook which allows the cup to turn around a pin, P, and second, as a cam follower. By means of a cam, E, turned by a crank, F, the cup is lifted to a specified height and dropped upon a polished base block, G, of hard rubber of quality which can be machined. The height to which the cup is lifted is adjusted by means of an adjustment plate, H, carrying the pin, P, and held in place by two screws, I.

This adjustment—to the height of 1 centimeter in the present instance—was the only calibration required and was made within an accuracy of ±0.2 millimeter. It was accomplished by means of a metal strip or gauge with a height of exactly 1.00 centimeter and strictly straight and parallel edges. The procedure for making this calibration was as follows.

The point where the cup came in contact with the base, which appeared as a small shiny spot on the cup after it dropped a number of times, was located. Then the adjustment plate was fixed in such a position that the height of drop was approximately 1 centimeter and the crank turned so that the cup reached its maximum height. In this position the shiny spot referred to before was readily observed, although a flash light was of appreciable assistance in this respect. The gauge was then placed with one side upon the base in such

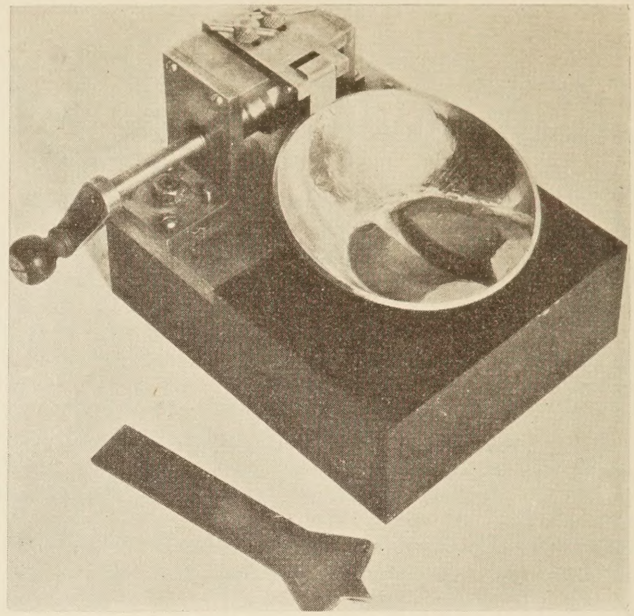

FIGURE 2.—MECHANICAL DEVICE FOR MAKING THE LIQUID LIMIT TEST

a manner that the height of its top side could be compared with the height of the shiny spot on the cup. The adjustment plate was then loosened and tightened at other positions successively until the height of the spot was equal to that of the top side of the gauge. The screws of the adjustment plate were now tightened so as to make it impossible to unscrew them by hand.

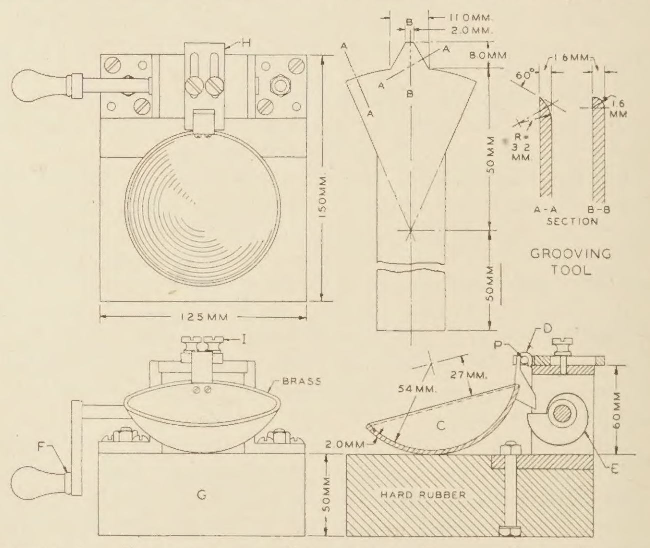

FIGURE 3.—CONSTRUCTION DETAILS OF LIQUID LIMIT DEVICE

In Figure 4 it can be seen that the height of drop (h_A) of point A_1 is greater than the height of drop (h_B) of the tangent to the lowest point B above the base. The difference (Δh) is dependent upon the relative position of points R, A, and C.

Had the device been designed so that no calibration were possible the whole apparatus would have required the type of very accurate workmanship furnished only by those specializing in the construction of scientific apparatus. In the design described above, however, the few dimensions (see fig. 3) specified, required only the ordinary accuracy furnished by any good workshop.

The grooving tool is made of tool steel to the dimensions shown in Figure 3 and hardened after the dimen-

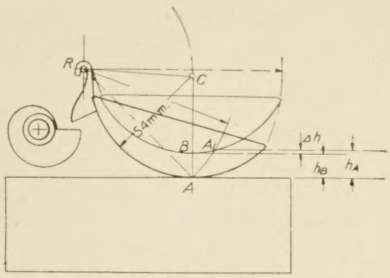

FIGURE 4.—HEIGHT ADJUSTMENT ON LIQUID LIMIT DEVICE

sions are checked. The dimensions of the groove exert an important influence on the outcome of the tests. Therefore, those dimensions of the grooving tool which control the cross-section of the groove had to be made with precision. They are the width of the top, 11.0 millimeters; the width of the bottom, 2.0 millimeters; and the height, 8.0 millimeters.[8]

THE FLOW CURVE AND ITS PHYSICAL SIGNIFICANCE

Instead of giving the liquid limit directly, tests performed with the mechanical device just described disclose the number of blows required to close the groove in soils at different moisture contents. The curve representing the relation between water content and number of blows is called the flow curve.

The flow curves are similar in character to the voids ratio-pressure curves as determined by means of confined compression tests ((8, 10) and Figures 16 and 17). They may be represented by the following equation

$$w = -F. \log N + C \qquad (1)$$

in which

w = moisture content in per cent of weight of dry soil
F = constant, called "flow index"
N = number of blows
C = constant

According to equation 1 the semilogarithmic plots of the flow curves with the water content on the arithmetic scale and the number of blows on the logarithmic scale are straight lines. Plotting the flow curves in this manner is advantageous in several respects.

The flow curves can be drawn from a few reliable points; mistakes can be detected much more easily on the straight-line semilog than on the curved-line arithmetic plot; and finally, the flow index, F, is in this manner defined as minus the slope of the semilog plot. This equals the range in moisture content corresponding to the number of blows represented by one cycle on the logarithmic scale. Under ordinary conditions of test it is convenient to take the variation in moisture content corresponding to the cycle between 10 and 100 blows as the flow index.

Figures 5 and 6 show the flow curves of a number of soils. For the majority of soils, the points fall very close to straight lines. For some soils the points are scattered over a wider strip, although the best curves through them are straight lines. The scattering of points shown in the case of soils 7–0–2 and 49–1–1 is due to the fact that these fat clays are extremely difficult to mix into a uniform paste with their natural water content. The points of the flow curve of soil 1–93–1, dried once, are scattered on account of the very dry air in which these tests were run.

[8] According to the bureau's investigation at its subgrade laboratory in Washington the tool described here and the one described in the Bureau's procedures (9) may serve equally well in tests performed on plastic soils, and the latter seems to be especially desirable for tests on the nonplastic soils.

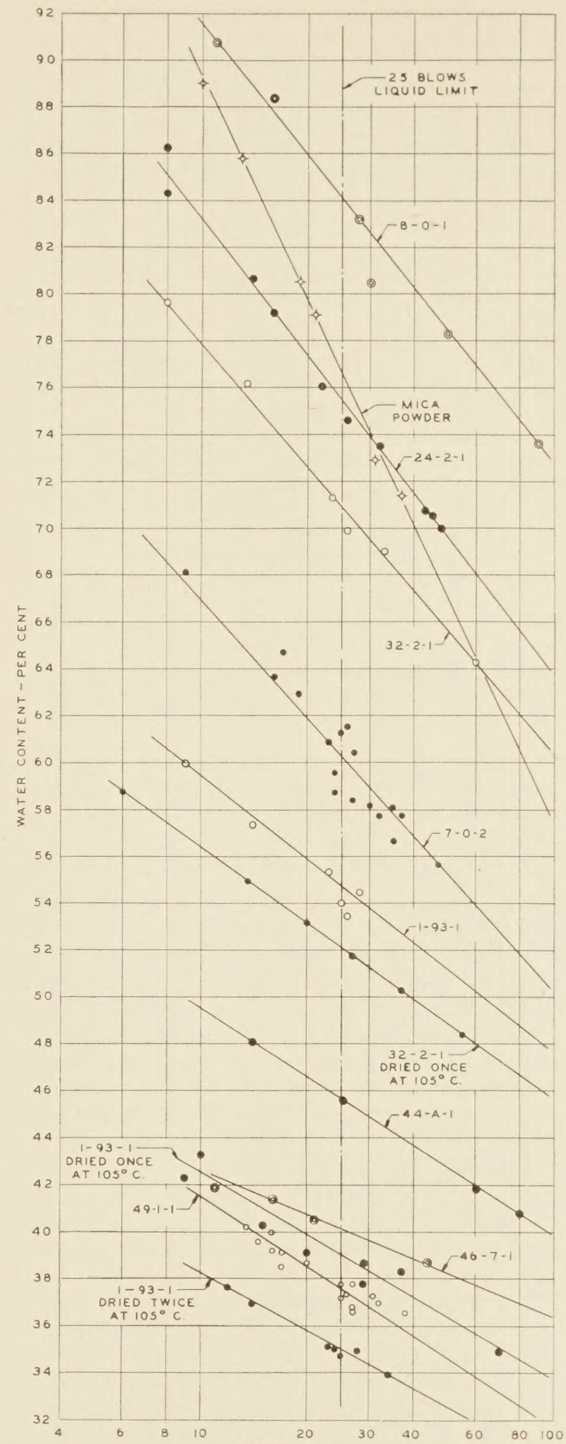

FIGURE 5.—EXAMPLES OF FLOW CURVES

In order to understand the physical significance of the flow curve and its dependent constants, one should remember that the force resisting the deformation of the sides of the groove is the shearing resistance of the soil. Hence, the number of blows required to close the groove of a soil paste represents a relative measure of the shearing resistance of this soil at this water content. It follows that the shearing resistance of all soils at the liquid limit must have a constant value (6).

This shearing resistance, as indicated by a great number of comparisons of liquid limits determined by hand by different operators, and the results of the tests which the mechanical device with a height of drop of

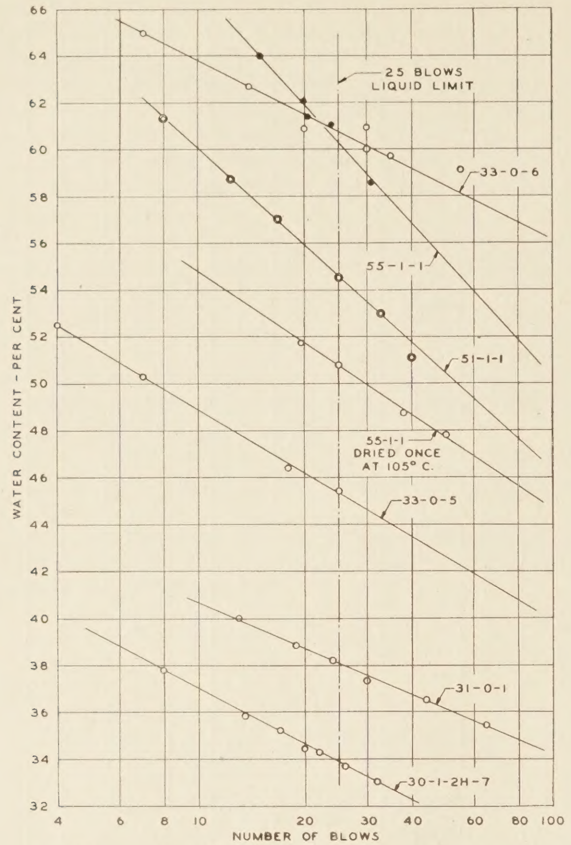

FIGURE 6.—EXAMPLES OF FLOW CURVES

one centimeter equals that possessed by the soil when requiring 25 blows to close the groove.

The shearing resistance of a given soil at the plastic limit may be many times that of the same soil at the liquid limit. There is also a wide variation in the shearing resistance of different soils at the plastic limit. This difference may be felt by hand when performing the plastic limit test on various soils. For clays this difference is commonly expressed as difference in toughness. The toughness of a clay at its plastic limit may therefore be described as the maximum stiffness or shearing resistance which it can acquire without losing its plasticity. Hence, the shearing strength at the plastic limit may be considered a measure of the toughness of a clay.

The flow index may be used as an approximate criterion for the relative magnitude of the shearing resistance of different soils at the plastic limit. In order to illustrate this relationship let us consider two soils with the same plasticity indices but different flow indices. The flow curves of these soils are shown in Figure 7. When the water content is reduced from the liquid limit by the same amount Δw, the increase (ΔN) in number of blows required to close the groove, will be smaller for the steeper flow curve.

Therefore, in Figure 7, ΔN_B is greater than ΔN_A, and the increase in number of blows is also a measure of the increase in shearing resistance. Hence, soil B will increase its shearing resistance at a faster rate when subjected to drying than soil A.

The number of blows, N, may be regarded as representing a force equal to N times the force exerted in the application of a single blow. The shearing resistance of a soil, however it may be measured, is obviously proportional to the force required to produce a given deformation (in this case the closing of the groove). It follows that N, in equation 1, may be taken as proportional to s, the shearing resistance of the soil; and we may write

$$W = -F \log s + C \qquad (2)$$

If s were expressed in physical units the value of the constant C would be different from that in equation 1. Otherwise the equation would be unchanged.

This relation is also correct in the range near the plastic limit according to investigations by Terzaghi and Janicsek. (See (11) p. 560.) Hence, we may assume that in the whole range between the liquid and the plastic limit the relation between shearing resistance and water content, on a semilogarithmic plot, is represented by a straight line.[9]

It should be noted that the term "flow curve," as used in this report, represents the relation between the shearing resistance (measured indirectly by means of number of blows) and the water content. In some publications on the subject of viscous and plastic flow the term "flow curve" is applied to the graphical representation of the relation between velocity (or quantity) and pressure for a fluid at a constant temperature, i. e., in the case of soil, for a paste with a constant water content.

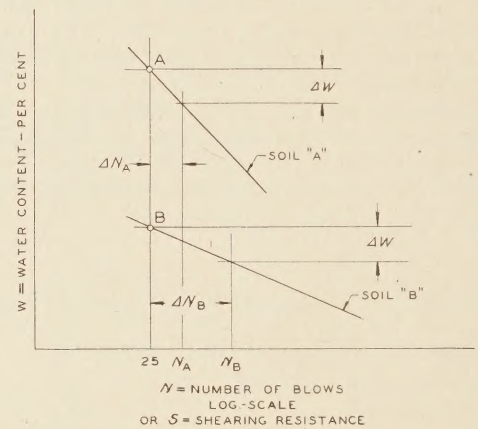

FIGURE 7.—DIAGRAM ILLUSTRATING RELATION OF FLOW CURVE AND SHEARING RESISTANCE

Assuming that the soils A and B in Figure 7 have the same plasticity indices and that this value is represented by (Δw), we draw the following conclusions:

The shearing resistance at the plastic limit of soils having the same plasticity indices is inversely proportional to the flow index. The shearing resistance at the plastic limit of soils having the same flow index but a different plasticity index is proportional to the plasticity index. Soils having the same plasticity and flow indices are, from the standpoint of shearing resistance in remolded state, alike.

In order to classify clays according to their toughness it would be necessary to determine the shearing resistance at the plastic limit by means of a direct shearing test or an unconfined compression test. An approximate measure for this quantity can be derived from equation 2 and Figure 7, using the following symbols:

L = liquid limit
P = plastic limit
$I = L - P$ = plasticity index
F = flow index
s_1 = shearing resistance corresponding to the liquid limit = constant for all soils

[9] Investigations by B. A. Keen and G. W. Scott Blair (7) have yielded a relationship between the water content and the shearing resistance ("static rigidity") which appears similar to the flow curves of Figures 5 and 6 when plotted on arithmetic graph paper.

s_2 = shearing resistance corresponding to the plastic limit = toughness

Then T, the index of toughness at the plastic limit, is derived as follows:

$L = -F \log s_1 + C$

$P = -F \log s_2 + C$

$L - P = I = F (\log s_2 - \log s_1)$.

$$\log \frac{s_2}{s_1} = \frac{I}{F} = T \quad (3)$$

Instead of solving equation 3 for s_2 it is simpler to use the logarithm of the ratio between the toughness s_2 and the constant s_1 as a relative measure for the toughness which we define tentatively as toughness index T. According to equation 3 this index T is equal to the ratio of the plasticity index and the flow index.

The relative magnitude of toughness indices shown in Table 1 agrees well with the general character of these soils. Samples Nos. 7–0–2, 24–2–1, 31–0–1, 33–0–6, 44–A–1, and 55–1–1 represent tough clays. Soils which are friable at the plastic limit are the silt No. 1–93–1, when oven-dried, the kaolin No. 51–1–1, and especially the mica powder.

It may be concluded from this discussion that Atterberg's liquid and plastic limit values, supplemented by the flow index, reflect the shearing resistance of a plastic soil in remolded state at different water contents.

TABLE 1.—*Values obtained from Atterberg tests*

Soil No.	State of soil	Liquid limit	Flow index	Plastic limit	Plastic index	Shrinkage limit	Toughness index	Organic carbon content
		Per cent		*Per cent*	*Per cent*	*Per cent*		*Per cent*
1–93–1	Natural	54.7	11.8	32.7	22.0	28.7	1.86	2.48
1–93–1	Dried once	39.0	8.8	29.2	9.8	-------	1.11	-------
1–93–1	Dried twice	34.9	8.2	27.5	7.4	-------	0.90	-------
7–0–2	Natural	60.6	19.1	23.7	36.9	13.3	1.93	0
8–0–1	Natural	84.0	18.8	49.5	34.5	45.0	1.84	2.60
8–0–1	Dried once	51.0	-------	42.0	9.0	-------	-------	-------
24–2–1	Natural	75.4	19.5	30.8	44.6	13.0	2.29	0
30–1–2H–7	Natural	33.8	8.0	21.6	12.2	17.3	1.52	0
31–0–1	Natural	38.0	6.5	21.9	16.1	20.4	2.48	0.65
32–2–1	Natural	70.8	17.5	28.3	42.5	16.7	2.43	2.00
32–2–1	Dried once	52.1	10.7	25.5	26.6	-------	2.48	-------
33–0–5	Natural	45.3	8.9	28.5	16.8	30.6	1.89	-------
33–0–6	Natural	60.8	7.7	40.1	20.7	38.8	2.69	-------
44–A–1	Natural	45.6	9.6	25.2	20.4	-------	2.12	0
46–7–1	Air dry	40.1	6.2	23.2	16.9	9.5	2.72	0
49–1–1	Natural	37.5	9.9	21.8	15.7	16.8	1.58	0
51–1–1	Air dry	54.6	13.9	33.5	21.1	29.8	1.52	0
55–1–1	Natural	60.3	16.7	26.0	34.3	21.5	2.05	0
55–1–1	Dried once	50.7	9.7	24.4	26.3	21.5	2.71	0
Ground mica powder [1]	-------	76.6	32.0	55.6	21.0	-------	0.77	-------

[1] See fig. 12.

For nonplastic soils, this relation is probably not so well defined or may even be nonexistant on account of the higher permeability of the soil which causes flow of water toward the groove under the influence of the blows. These sudden volume changes and the hydrodynamic friction (10) which replaces the actual shearing resistance of the soil obscure the physical significance of the liquid limit of nonplastic soils.

PROCEDURE FOR DETERMINING THE LIQUID LIMIT AND THE FLOW INDEX

The liquid limit was determined for soils in both their original wet state and in the dried and powdered state. In both cases a quantity of about 100 to 200 grams was thoroughly mixed and then worked up with distilled water, a spatula being used as a mixing tool, to a soil paste at approximately the liquid limit.

A small amount of this paste was then placed in the cup and smoothed off, as shown in Figure 2. The grooving tool, held perpendicularly to the point of contact, as shown in Figure 8, was drawn through the sample along the diameter through the center line of the cam follower. This was accomplished best by holding the cup in the left hand with the cam follower turned upward and away from the body. The grooving tool was held with the rounded edge toward the body and in contact with the sample. The groove was formed by drawing the tool away from the cam follower.

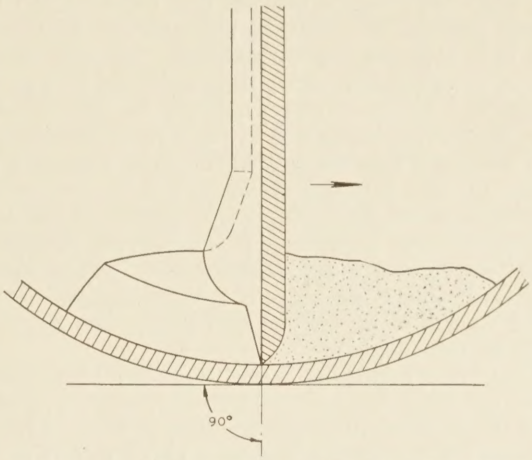

FIGURE 8.—LONGITUDINAL SECTION THROUGH CENTER OF GROOVE, SHOWING GROOVING TOOL

With clays, a clean groove could generally be made with one stroke. Nonuniformity of the mixture, however, or sometimes the presence of coarse soil grains, tended to cause the sides of the cut to become scratched or torn locally. In such cases the sample had to be mixed and grooved again.

With some soils, especially sandy soils and soils containing organic matter, it was not possible to draw the grooving tool through the sample without tearing the sides of the groove. In such cases the groove had to be worked out gradually. When the test was run on sands it was necessary to form the groove by means of a spatula and to use the grooving tool merely for checking the dimensions of the groove.

As soon as a satisfactory groove had been made, the cup was placed on its carriage in the apparatus and the device was placed on a horizontal bed of shock absorbent material such as a layer of magazines. The purpose of this bed was to insure a constant mass, namely, that of the hard rubber block, against which the cup would strike during the test. Had the apparatus been laid on a table or clamped to it, the elastic properties of the mass upon which the cup fell would have been subject to change. Although the influence of this change upon the resulting impacts was found to be small, it was measurable and therefore, its elimination by the above means seemed desirable.

With the crank turning at the rate of about two rotations per second, the number of blows required to cause the two sides of the sample to come into contact at the bottom of the groove along a distance of about half an inch were recorded.

This operation of mixing, grooving, and recording the number of blows required to close the cut was repeated until a close agreement was observed in the number of blows required in three successive determinations. Generally, not more than three determinations were required on humid days. Because of the slow evaporation in such cases the variation in the number of blows of all three determinations on a carefully mixed sample was not larger than two blows.

Greater differences on humid days were attributed to nonuniformity of the sample. In such cases the determination of the number of required blows was repeated until the sample was mixed sufficiently to give consistent results. The average number of blows for the last three determinations was then considered as the correct value.

The effect of evaporation on dry days caused a regular and gradual increase in the number of blows required in successive determinations. In such cases the last one of at least three determinations was used, provided the values formed a fairly regular increasing series. However, there was always an uncertainty connected with the test when performed in very dry air.

As soon as the number of blows had been determined with sufficient accuracy, about 10 grams of the sample were transferred into a pair of watch glasses and weighed for moisture determination. Part of the sample around the closed groove was selected for this purpose in order to reduce the error due to nonuniformity of the sample.

The above operations were repeated at a sufficient number (at least five) of different moisture contents to furnish the data required for the flow curve. After each moisture-content determination a small quantity of the original soil mixture was put into the brass cup to replace that part removed into the watch glasses and the test performed at another moisture content.

Since the moisture content corresponding to 25 blows equals the liquid limit as performed by hand, it was deemed desirable when determining the liquid limit with the device, to use trial water contents until the consistency of the sample was such that the required number of blows ranged between 20 and 30. Until this consistency was reached no moisture content determinations were made. After it was reached but three determinations were made. Depending on whether the first sample required less than 25 or more than 25 blows, the water content of the second determination was decreased or increased. For the third test the water content was changed again in such a manner that the three points which determine the flow curve (water content against number of blows, see fig. 9) lie in the vicinity of the 25-blow ordinate. The intersection of the flow curve with this ordinate corresponds to the liquid limit.

Table 2 is selected at random from the laboratory records of the writer to serve as an example for liquid-limit determinations by means of the device. The results of these tests are shown in Figure 9.

Sample No. 30–1–2H–7 in Table 2 was tested on a very humid day. The first determination showed, nevertheless, irregularities in the number of blows.

Table 2.—*Data sheet for representative liquid limit determinations made on soil No. 30–1–2H–7 with the mechanical device on a humid day*

Number of blows, or state of soil	25, 30, 32, 32	21, 23, 22	24, 26, 26	At plastic limit	
Watch glasses No	J	H	B	V	U
Weight wet, W_1, grams	38.71	36.25	36.98	30.987	25.354
Weight dry, W_2, grams	36.30	33.75	33.49	30.180	24.613
Weight glasses, W_3, grams	28.99	26.46	23.09	26.443	21.184
W_1-W_2	2.41	2.50	3.49	0.807	0.741
W_2-W_3	7.31	7.29	10.40	3.737	3.429
$w=\frac{W_1-W_2}{W_2-W_3}\times 100$	33.0	34.3	33.6	21.6	21.6

Liquid limit: L=33.7 per cent.

A detailed analysis of the causes of such irregularities and of the influence of different variables upon the accuracy of the determinations are treated later in this report.

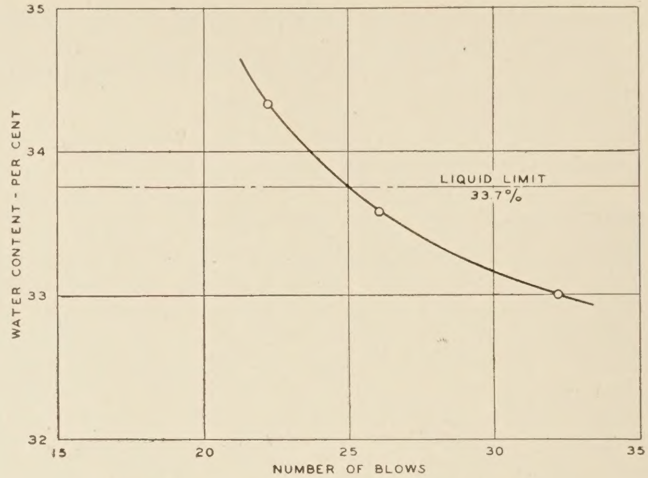

Figure 9.—Flow Curve for Soil 30–1–2H–7

In Table 2, the Figures 25, 30, 32, and 32 represent the number of blows of successive trials for the same sample (watch glasses J). The large difference between the first trial, 25, and the second trial, 30, indicates that the sample was not mixed sufficiently. The third attempt required 32 blows. The agreement between the second and the third attempt was considered sufficient. The correct value could have been taken as either the average, 31, or the last value, 32. In this case the consistency was checked a fourth time and the result, 32, was taken as representing the correct number of blows.

In the second determination of the consistency (watch glasses H) the number of blows of three successive trials was 21, 23, and 22. The last number was used for plotting the flow curve.

The third determination of the consistency (watch glasses B) gave the following three values, 24, 26, and 26.

Those numbers used for plotting the flow curve are shown in boldface type.

Table 3.—*Data sheet for representative liquid limit determinations made on soil No. 49–1–1 with the mechanical device on a dry day. Soil was dried twice*

Number of blows	18, 22, 27, 30	25, 23, 31, 35	15, 16, 17, 18	21, 22, 25, 27
Watch glasses No	E	A	G	H
Weight wet, W_1, grams	41.19	46.62	53.49	45.35
Weight dry, W_2, grams	39.02	43.71	50.49	42.57
Weight glasses, W_3, grams	33.04	35.45	42.46	35.03
W_1-W_2	2.17	2.91	3.00	2.78
W_2-W_3	5.98	8.26	8.03	7.54
$w=\frac{W_1-W_2}{W_2-W_3}\times 100$	36.3	35.2	37.4	36.8

The effect of the humidity can be seen by comparing Table 2 with Table 3. In the first case the variations in the numbers are small and chiefly due to inconsistencies in the mixture. In Table 3 each number is somewhat larger than the previous one. The first consistency determination gave the following numbers: 18, 22, 27, and 30. There is sufficient regularity in the increase of the series to warrant the assumption that 30 blows represent the consistency of the sample when placed in the watch glasses.

FACTORS INFLUENCING THE ACCURACY OF THE DETERMINATIONS

Among the factors investigated in this connection were: (*a*) Uniformity of mixture; (*b*) degree of drying the sample; (*c*) humidity of air at the time of test; (*d*)

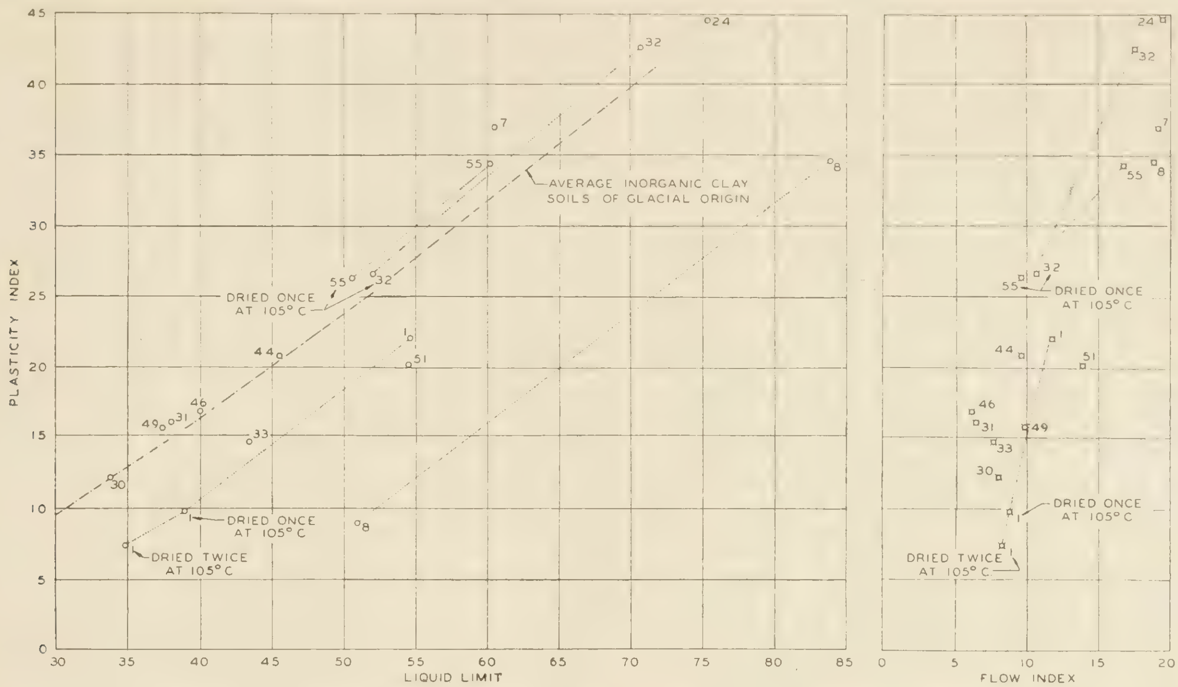

FIGURE 10.—RELATION BETWEEN LIQUID LIMITS AND PLASTICITY INDICES

temperature at the time of test; (*e*) accuracy of the height of drop and of dimensions of grooving tool; (*f*) weight of cup and quantity of soil used; (*g*) cleanliness of apparatus and wear on the points of contact between base and cup; (*h*) soil character.

(*a*) *Uniformity of mixture.*—It was especially difficult to obtain a uniform mixture when the test was started from the original state. Samples of very uniform clay deposits were found to consist of layers with different physical characteristics, resulting probably from variations in the formative sedimentation processes. Increase in the colloidal content of soils tends to increase the difficulty of obtaining uniform mixtures. In such cases the sides of the grooves were likely to contain streaks of soil whose true cohesion had not been entirely broken up. This condition appeared to be the cause of irregularities in the number of blows required to close the cut in successive trials, as well as a scattering of the points on the flow curve, as shown in the case of soil 7–0–2 (fig. 5) and soil 49–1–1 (fig. 6).

(*b*) *Degree of drying the sample.*—Flow curves determined for soils in the dried and powdered state will give very consistent results because the powder can be mixed more thoroughly than the natural wet soil. Drying soils, however, may cause a slight drop in the liquid and plastic limits. Oven drying of some soils may cause a very appreciable drop in the limits and for this reason soils are air dried in the routine subgrade tests.

This drop is especially important in the case of soils containing organic matter. Their liquid and plastic limits change somewhat when exposed to air and considerably when they are oven dried. In Table 1 examples of this kind are represented by an organic clay soil from Turkey (No. 32–2–1), an organic silt from Cambridge, Mass. (No. 1–93–1), and an organic clay from New London, Conn. (No. 8–0–1).

The drop of plastic and liquid limit due to drying is represented graphically in Figure 10. It will be noticed that the drop occurs along approximately parallel lines. The trend of these lines is the same as that of the very flat curve representing the relation between liquid limit and plasticity index for average inorganic clay soils of glacial origin, shown in Figure 10 as a dot-dash curve.

The plastic and liquid limits of most inorganic clay soils display slight decreases after drying. However, this drop is very small, and it was found that by saturating the soil for several days the original plasticity could often be restored. The only inorganic clay soil for which the plasticity decreased an appreciable amount as a result of oven-drying is soil No. 55–1–1, a marine clay deposit from the St. Lawrence River Valley, Quebec. From the graphical representation in Figure 10 it can be seen that this decrease is only about one-half of the decrease observed for the three soils with organic content.

Apparently the cause of this phenomenon is the baking together of the grains of colloidal size. Most inorganic colloids seem to be reversible, while organic colloids are partially destroyed even at temperatures of 105°C. and therefore must be considered as irreversible.

(*c*) *Humidity of air at time of test.*—On very dry days the evaporation of moisture from the sample proceeded fast enough to make subsequent determinations of the number of blows appear as a rapidly progressing series of numbers. Therefore, in order to prevent additional irregularities in this series on account of differences in water content, the samples had to be mixed quickly and thoroughly after each trial. In addition the mixture which was used for test was protected from evaporation during the test and, furthermore, the transfer from the tested soil cake to the watch glasses was carried out as quickly as possible.

(*d*) *Temperature at time of test.*—A series of tests by Atterberg (Table 4), which were carried out at 7° and 24° C., show practically no effect of the temperature. A few careful tests which the writer performed at temperatures between 35° and 40° C. showed no difference from the values obtained at 20° C.

(*e*) *Accuracy of height of drop and dimensions of grooving tool.*—As would be expected, it was found that the effect of the blows varies approximately with the square of the height of drop. Results of the tests are

Table 4.—*Effect of temperature on the liquid and plastic limit determinations*

Soil	Temperature	Liquid limit	Plastic limit
	Degrees C.	*Per cent*	*Per cent*
1	7	31.5	25.7
	24	30.5	26.0
2	7	41.6	25.0
	24	40.5	23.8
3	7	24.5	18.9
	24	24.4	17.6
4	7	58.8	52.8
	24	58.9	53.9

shown in Figure 11. An error of 0.1 millimeter in adjustment of the height was found to correspond with a change of 2 per cent in the number of blows. Adjusting the height of drop within an accuracy of ±0.2 millimeter proved satisfactory for ordinary purposes.

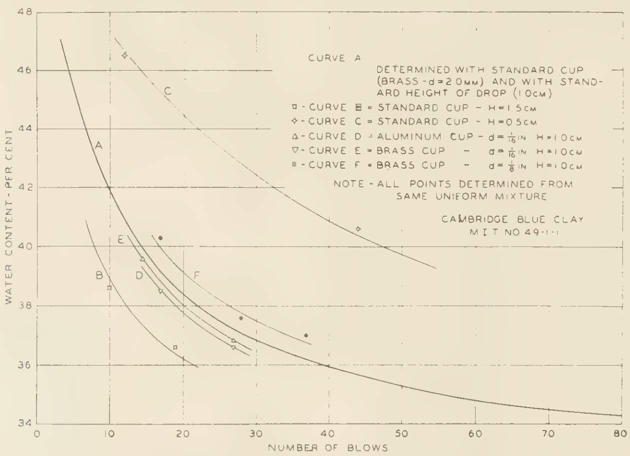

Figure 11.—Influence of Weight of Cup and Height of Drop upon Flow Curves

Test results indicate that that dimension of the grooving tool which determines the width of the bottom of the groove should be accurate within ±0.05 millimeter.

(*f*) *Weight of cup and quantity of soil used.*—Figure 11 also gives the results of tests to determine the effect of weight of cup. The results show that the number of blows required to close the cut increases slightly with the weight of the cup. The weight of the standard cup, including the cam follower, is 200 grams, and should be adhered to within 10 grams.

As expected, the tests show that the quantity of soil has no appreciable influence on the test results. The quantity should be large enough to permit the cutting of a well-shaped groove.

(*g*) *Cleanness of apparatus and wear on the points of contact between base and cup.*—A drop of water or small quantity of soil, located at the point of contact between the cup and base, will reduce the effect of impact to a considerable degree and cause appreciable errors. Wear on the points of contact between base and cup have not been found to produce appreciable error.

(*h*) *Character of soil.*—Difficulties were encountered in determining the flow curves of nonplastic soils, largely because of insufficient adhesion to the cup and excessive permeability, the latter property causing excessive water content in the region of the groove. Preliminary tests indicate that the principle of the flow table, as used in cement and concrete testing, would provide a more suitable apparatus for the determination of the flow curves of nonplastic soils than the liquid-limit device in its present form.

CONSIDERATIONS IN THE PRACTICAL USE OF THE CONSISTENCY LIMITS

In order to understand thoroughly the practical use of the limit tests, one should have some conception of (*a*) the effect of grain size and shape of soil grains and (*b*) the effect of the structure on the plastic properties of the soil.

(*a*) *Effect of size and shape of grains.*—The hypothesis that plasticity and other important properties of clay are caused by the presence of scalelike particles was first advanced by Voigt in 1897. Later, and independently, other scientists arrived at the same conclusion. Reliable evidence for the truth of this assumption was, for the first time, presented by A. Atterberg (12).

Professor Terzaghi (10 and 11) observed that clays have a much lower permeability than sands with the same equivalent grain diameter, and concluded that the volume of a clay particle must be much smaller than that of a bulky grain of the same size. This indicates that clay particles are of scalelike shape.

Professor Goldschmidt (13) succeeded in finding a satisfactory explanation for the action of scalelike particles in soil. He showed that the surfaces of scalelike particles are charged with electricity wich affects the arrangement of the bipolar molecules in a liquid like water. When the clay powder is mixed with a liquid consisting of molecules which are not distinctly bipolar (e. g. carbon tetrachloride), the mixture does not acquire plasticity. The percentage of scalelike particles in common clays varies between 10 and 30 per cent, of which only that fraction smaller than about 0.2 micron (equivalent grain diameter) may be considered effective from the standpoint of plasticity.

From the above information it follows that in most cases the grain-size distribution of a soil does not yield any information on plasticity. As a striking example, let us compare the grain-size curves of a plastic clay, quartz powder,[10] feldspar powder,[10] and mica powder,[10] shown in Figure 12.

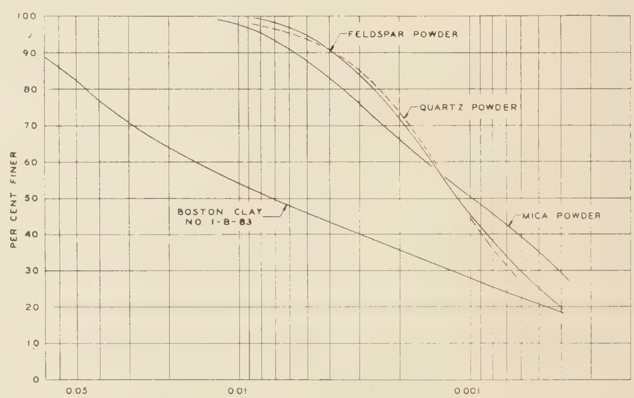

Figure 12.—Grain Size Curves of Quartz, Feldspar, and Mica Powders, Compared with a Plastic Clay

The ground quartz and feldspar consist of bulky grains and have no plasticity. The ground mica is slightly plastic. Table 5 contains a comparison of the plasticity of these four materials with the percentage of grains smaller than 5 microns (clay according to the U. S. Bureau of Chemistry and Soils), smaller than 2 microns (clay according to the international classification), and smaller than 0.2 micron. The information contained in Figure 12 and in Table 5 was furnished by Dr. L. Jurgenson.[11]

[10] Ground wet in a ball mill.
[11] Research associate, Massachusetts Institute of Technology.

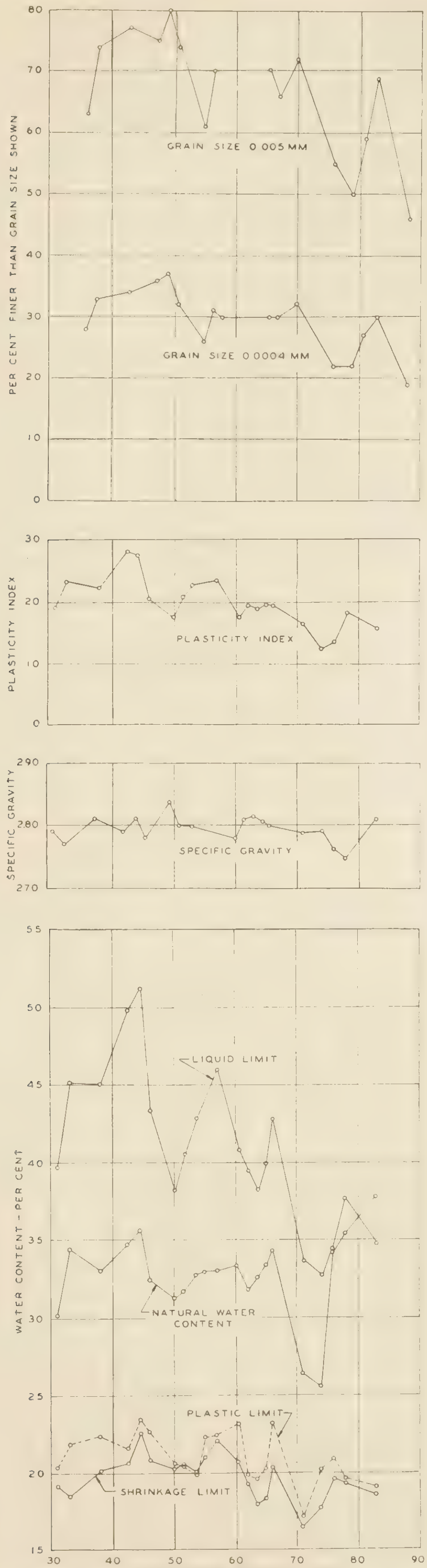

Figure 13.—Comparison of Variation of Limit Values and Grain Size in Soil Layers at Different Depths

Different soil layers from the same deposit are often related in character so that changes in grain-size distribution may reflect a corresponding change in plasticity. An example is shown in Figure 13.

Table 5.—*Comparison of grain size and plasticity for different materials*

Material	Liquid limit	Plasticity index	Less than 5 microns	Less than 2 microns	Less than 0.2 micron (estimated)
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Boston clay, No. 1-B-83	35	16	46	36	12
Mica powder	76.6	21	88	66	12
Quartz powder	No plasticity		94	74	4
Feldspar power	No plasticity		95	72	8

(*b*) *The effect of the structure of clay*—The mechanical properties of clay below the zone of weathering and in undisturbed state are different from the properties of a sample which is thoroughly remolded. A detailed discussion of the structure of undisturbed clay is beyond the scope of this report. The reader is referred to (15) and (16). As an example for the effect which remolding has on the physical properties of clay, the pressure-void ratio diagrams for an undisturbed clay and the same clay remolded, are shown in Figure 14.

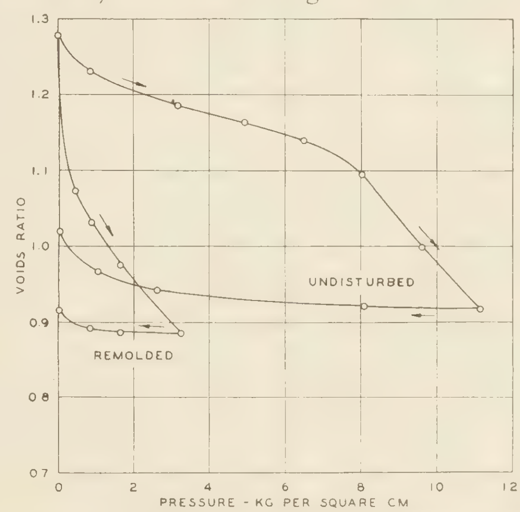

Figure 14.—Relation Between Pressure and Voids Ratio in Undisturbed and Remolded States, for Laurentian Clay, No. 56-103

Since the liquid and plastic limit tests can be performed only after the natural structure of the clay is destroyed by remolding, they are incapable of reflecting any mechanical properties of the clay in undisturbed state. Consequently, at the liquid limit a clay deposit may have very appreciable strength, whereas the shear resistance of the same soil at the liquid limit, remolded, will be very small. Some Laurentian clays may be so rigid at the liquid limit that they can carry a building load of 5 tons per square foot without excessive settlement.

In contrast to the liquid and the plastic limits it is interesting to note that the shrinkage limit can be determined in both the undisturbed and the remolded state (9). The results may differ in varying amounts depending upon the structure of the soil. The difference in shrinkage limits when determined from both the undisturbed and remolded state may be especially useful in estimating rapidly the structural characteristics of the material. Table 6 illustrates the difference observed between shrinkage limits of a soil in the remolded and undisturbed state and also shows that the plastic limit may be lower than the shrinkage limit in the undisturbed state.

TABLE 6.—*Tests on samples in both the disturbed and the undisturbed states*

Type of clay	Laurentian clays		Boston clay
Sample number	55-1-1	56-D-1	49-1-SP
	Per cent	*Per cent*	*Per cent*
Water content in natural state	56.2	38.0	30.6
Plastic limit from natural wet state	26.0	23.0	21.5
Shrinkage limit undisturbed	34.7	28.6	20.3
Shrinkage limit remolded	21.5	20.7	16.3

SELECTION OF SAMPLES FOR FINAL TESTS ILLUSTRATED

Glacial and river deposits are often nonuniform, varying from coarse sands and gravels to plastic clays. In such cases a great number of soil samples must be taken from borings or test pits in order to investigate these deposits for foundation purposes. For a rapid classification of these samples, to facilitate the selection of a few representative ones for more elaborate tests (compressibility, shearing resistance, etc.) (14) Atterberg's liquid and plastic limit tests prove very satisfactory.

The distribution of nonplastic silt and sand layers is of utmost importance for computing the rate of settlement. Even very fine layers of more permeable material will act as drains for water which is pressed out of the compressible clay layers during the process of consolidation.

The ability of the limit tests to disclose differences in soil, visibly the same, is illustrated by Figure 13, referred to previously. These soil samples of Boston clay were taken at different elevations in the same drill hole in an investigation of building settlement carried on under the supervision of Prof. Glennon Gilboy. In spite of the fact that the samples showed the clay deposit to be uniform in color and appearance and without any stratification, the limit tests disclosed important differences in the different samples.

In this manner they facilitated the selection of sample for the determination of the consolidation characteristics by means of confined compression tests (8).

SUMMARY

The foregoing investigation indicates that reliable results are to be expected from the use of the flow curve apparatus under the following conditions:

(1) That the device be calibrated to an accuracy of 0.1 millimeter for a height of drop of one centimeter.

(2) That the device be placed in a horizontal position and be cushioned by relatively soft material, such as newspapers or magazines.

(3) That the surface of the base and the outside of the cup be wiped free of moisture or soil powder before the number of blows are determined.

(4) That the sample be carefully mixed before the test is performed, especially when it is started with soil in the natural wet state.

(5) That a straight groove be made by holding the cup in one hand, cam follower turned upward and away from the body, and drawing the standardized grooving tool toward the body along a line passing though the center line of the cam follower and the point of contact between cup and base in the manner previously described. (Fig. 8.)

(6) That the crank be turned at the rate of two rotations per second until the bottom of the cut is closed for a distance of about one-half inch.

(7) That the operations be repeated until the last three numbers of blows are in substantial agreement.

(8) That at least two or three determinations be made at different water contents in the vicinity of 25 blows for the determination of the liquid limit, and at least five determinations, ranging between 10 and 40 blows be made for the determination of the flow curve and the flow index.

Irregularities in successive determinations of the number of blows were found to be due to—

1. Irregular shape of groove, side walls scratched due to inconsistencies of sample or because the edge of the grooving tool was not cleaned.
2. Nonuniform mixture of sample in natural state or rapid evaporation and insufficient mixing after every determination.
3. Grooving tool held at different angles instead of perpendicular to the tangent at the point of contact.
4. Moisture or dry soil powder on the points of contact of base and cup.

Generally, with respect to the plasticity tests it was found that—

(1) The flow curve on a semilogarithmic plot is a straight line.

(2) The liquid limit is the water content corresponding to 25 blows as determined by means of a standardized device and procedure.

(3) The flow index is a constant indicating the slope of the flow curve when plotted on semilogarithmic paper. It is equal to the difference of the water contents corresponding to 10 and to 100 blows.

(4) The liquid and plastic limits of soils determined with their natural water content are for inorganic clay soils equal or slightly higher than the limits determined from oven-dried state. For soils containing organic matter, the difference may be very large.

(5) The change in plasticity caused by drying is accompanied by a change in other physical properties, especially the cohesion and the permeability of the soil.

(6) The liquid limit is the water content at which the raw material of a soil in remolded state possesses a very small but constant shearing resistance.

(7) The shearing resistance at the plastic limit may be different for different soils. The flow index may be used as a relative measure of this difference.

(8) For soils having the same plasticity indices, the shearing resistance in remolded state at the plastic limit is inversely proportional to the flow index.

(9) For soils having the same flow indices, the shearing resistance in remolded state at the plastic limit is proportional to the plasticity index.

(10) Soils having the same plasticity and flow indices, have the same shearing resistance in their remolded state at corresponding intermediate states.

(11) The difference between the shrinkage limit in undisturbed and remolded state is caused by the character of the structure in natural state, and therefore, may be used as a measure of the amount of disturbance resulting from thorough molding.

(12) The physical significance of the liquid limit of a nonplastic soil is fundamentally different from that of a plastic soil. It appears that this test when applied to slightly cohesive or cohesionless soils has more the character of a stability test.

(13) The plastic and liquid limit, and the flow index yield qualitative information on the shearing resistance of the soil in remolded state.

(Continued on p. 136)

THE NEW HAMPSHIRE TRAFFIC SURVEY

Reported by L. E. PEABODY ,Senior Highway Economist, United States Bureau of Public Roads

DURING the summer of 1931 the State Highway Commission of New Hampshire cooperated with the Bureau of Public Roads in a survey of highway traffic upon the trunk-line, State-aid, and town road systems of New Hampshire. Field observations were taken at the same locations and with the identical schedule of operation as in an earlier survey [1] in 1926. Figure 1 shows the locations of stations at which field operations were carried on in 1926 and 1931, and a graphical comparison of 1931 traffic with the 1926 forecast.

When account is taken of the unpredictable shifts in highway traffic, the data obtained in this survey afford a reasonably close check upon the results of the 1926 survey and the traffic forecast made at that time.

Traffic observed in 1931 upon the 383 routes or sections of routes aggregated 470,992 vehicles per day, as compared with a forecast of 408,549 vehicles per day made five years earlier. Thus the traffic in 1931 was greater by 15.3 per cent than the amount forecast in 1926. This is the gross comparison, and there is wider divergence when the comparison is made for individual sections of routes.

TABLE 1.—*Comparison of 1926 traffic forecast with actual traffic in 1931*

Routes with average daily traffic—	Total motor vehicles		Ratio, 1931 to 1926
	Forecast, 1926	Actual, 1931	
Less than 200	8, 940	12, 953	1. 449
200 to 499	23, 390	39, 720	1. 698
500 to 999	56, 940	75, 639	1. 328
1,000 to 1,499	78, 550	95, 202	1. 212
1,500 or more	240, 729	247, 478	1. 028
	408, 549	470, 992	1. 153

In Table 1 the forecast and actual traffic are compared by specific classes of routes; that is, those with less than 200 vehicles per day, 200 to 499 vehicles per day, etc. This tabulation shows that the actual traffic was relatively higher than the forecast upon routes carrying less than 500 vehicles per day in comparison with the more heavily traveled routes. The aggregate traffic on all routes carrying 500 or more vehicles per day exceeds the forecast by less than 9 per cent. Upon the most important routes (those carrying 1,500 or more vehicles per day) the actual traffic exceeded the forecast by less than 3 per cent.

If the traffic of 1931 is compared with the traffic classification of routes [2] made in 1926, it will be found that the traffic classification, based on 1926 traffic and a forecast based on that traffic, is closely accurate. In general, the variation from the forecast is well within the ranges of the traffic classifications set up in the earlier report. These ranges of traffic density, rather than the individual figures, are the significant factors in the study of a highway system; and the differentials between the 1926 forecast and the 1931 traffic are insufficient to change appreciably the traffic classification of these routes as originally set up.

[1] Report of a Survey of Transportation on the State Highways of New Hampshire (1927). A number of stations which were not operated at their 1926 locations, and certain 1926 stations which were not occupied in 1931, are not included in the comparisons here given.

[2] Report of a Survey of Transportation on the State Highways of New Hampshire, 1927, p. 57 et seq.

While the relative variations are greatest upon the light traffic routes (Table 1) especially those carrying under 500 vehicles per day, variations on these routes represent relatively small numerical differences in traffic count. This point may be brought out in still another way: On more than half the 383 routes or sections of routes for which traffic was forecast, the actual traffic in 1931 checked within 200 vehicles per day, and on 82 per cent of all routes, the differences were less than 500 vehicles per day.

If the comparison be made by specific routes, much the same conclusions are reached, as is shown in Table 2. The routes in this table are arranged in order of magnitude of the 1931 traffic. Upon the heavily traveled routes, the 1931 traffic is slightly below that forecast and, as the traffic decreases, the forecast traffic becomes greater in relation to the observed traffic.

TABLE 2.—*Comparison of 1926 traffic forecast with actual traffic in 1931 by specific routes*

Route	Location	Average daily density of 1931 traffic	Differences from 1926 forecast
			Per cent
U. S. 1	From Massachusetts line via Seabrook, Hampton, and Portsmouth to Maine line.	8, 078	−8. 5
U. S. 3	Lakeport via Franklin, Concord, Manchester, and Nashua to Massachusetts line.	4, 577	−12. 4
101 and 101A	Keene via Peterboro and Milford to Nashua	1, 954	+12. 2
18	From Vermont line via Littleton, Twin Mountain, Glen, and Conway to Maine line.	1, 704	+10. 2
U. S. 3	Colebrook via Lancaster, Whitefield, and Twin Mountain to Plymouth.	1, 532	+19. 9
16 and 28	Conway via Ossipee and Milton to Rochester	1, 428	+20. 0

The greater increase in traffic upon the more lightly traveled routes is not definitely a result of congestion upon the heavy-traffic routes, but is probably due to improvement, in surface, alignment, and grade, of more direct routes and of the routes carrying the lighter traffic, as well as to the desire of motorists to avoid heavier traffic. In general, these routes of lighter traffic are less highly improved; but, despite the poorer conditions with respect to grade, alignment, etc., it may be possible to travel as comfortably and as rapidly upon them as upon the more congested routes. In many cases, new scenery is a factor in the choice.

The improvement in the light-traffic routes since 1926 has been extensive. For instance, travel on route 10 between Hanover and Woodsville now averages more than 1,500 vehicles daily. Route 111 from Wentworth to Orford, joining route 10 at Orford, has a traffic average of more than 480 vehicles per day, or three times the amount forecast for this section in 1926. The increase upon this relatively lightly traveled route is due wholly to the completion of route 111 with a surfaced road since the survey of 1926, as this trunk line was not improved at that time.

Many of the divergences between the 1931 forecast of the 1926 survey and the actual count in 1931 are due to the completion of existing trunk line layouts created by the legislature, upon which little or no construction was in existence at the time of the 1926 survey. The trunk line completion act of the 1929 legislature provided for the completion of all routes designated as trunk lines by the close of the 1930 construction season.

Construction activities of this period resulted in several differentials, of which the following are examples. At station 65 in Somersworth traffic on route 16 southeast to Somersworth was 2,256 vehicles per day less than the forecast, while traffic on route 16–A south to Dover was 2,489 vehicles per day more than the forecast. Traffic north on route 16 at this station was 3,300 vehicles per day or very close to the 3,230 vehicles per day forecast in 1926 for this route. The shift in southbound traffic from route 16 to route 16–A is clearly a result of the complete construction with modern pavement of route 16–A, a much shorter and better route for through traffic. The completion of route 16–A places it in the major traffic classification, for practically all but local traffic now utilizes this shorter direct route in preference to the more circuitous route 16, which has now become of secondary importance.

At station 99 traffic toward Exeter was within 91 vehicles per day of that forecast. Traffic on route 101–C was 241 vehicles per day less than the forecast traffic, while traffic on the shorter State-aid route to Hampton Falls was 151 vehicles more than forecast. The improvement of the shorter State-aid route has drawn traffic to it somewhat in preference to route 101–C. In addition this diversion indicates the general tendency for traffic to seek out shorter, more direct routes in good condition, in preference to main routes on which 'here is congestion, such as route U. S. 1, the adjoining heavily traveled highway.

Construction activities may show their effects upon the routing of traffic at a considerable distance from the location of the improvement and thus affect the accuracy of a forecast. For example, at station 72, several miles north of Berlin on route 16, highway construction projects were under way during the period of 1931 field work. Traffic on route 16 was 87 vehicles per day less than forecast, while the traffic on route 110 northwest of Berlin exceeded the estimate by 93 vehicles per day.

Again, traffic on U. S. 3 and U. S. 4 between Concord and Laconia via Franklin was much reduced from that estimated in 1926, because of construction on these sections, while the traffic on route 106 between Concord and Laconia was considerably in excess of the amount forecast. In this latter case the increase on route 106 is evidently due in great part to the completion of the original construction on this shorter and more direct route from Concord to Laconia through less populated territory, avoiding the city of Franklin and the larger town of Tilton with their accompanying traffic delays. The construction on route U. S. 3 in Franklin and Tilton was avoided to a great extent by the use of the State-aid route from Boscawen through Northfield to Tilton, upon which there was a traffic increase of approximately 50 per cent in excess of that forecast, because of the use of this optional route during the construction on U. S. 3. While a slight increase in traffic on route 106 may be attributed to construction on U. S. 3, check surveys operated by the State highway department between the 1926 and 1931 cooperative surveys have indicated a substantial increase in traffic on route 106 above a normal expected increase, which may be attributed wholly to the complete construction of this route, which under average conditions shortens the driving time between Concord and Laconia by from 15 to 30 minutes.

Although no construction took place at station 64 during the period of the survey, there is evidence of considerable change in traffic routed through this station. Traffic between Claremont and this station during 1931 was 1,742 daily vehicles, or very close to the forecast of 1,730 vehicles per day. Traffic west through Vermont on route 12 is 385 vehicles per day greater than the forecast, while the traffic north on the township road to Plainfield is 292 per day under the forecast.

Construction activities which permit the use of the highway produce less effect upon traffic movement on the lightly traveled routes. As an example, traffic on all routes leading from station 4 is in excess of that forecast, although highway construction during the period of the survey was noted at this station. The excess north on the township road to Lancaster was 32 vehicles, west on U. S. 2 to Riverton, 91 vehicles, and east on U. S. 2 to Jefferson, 65 vehicles per day.

Improvement of the Concord-Keene highway was completed in 1930. Although portions of this route were improved in 1926, there were many sections of the route awaiting improvement. The Wolfeboro-Alton section of route 28 was completed in 1930. Route 11 north of Alton to the junction of route 28 was heavily used by traffic during 1931 to avoid construction on U. S. 3. This section has been completed since 1926. On all of these sections the traffic use during 1931 was greater than the amount forecast in 1926.

At station 56, in Newport, at the junction of the State-aid road and route 11, the routing was changed so that traffic which formerly used route 11 west now goes down the State-aid road approximately one-fourth of a mile, and then turns west. This change accounts for the increase in traffic on the State-aid road at this point. At station 11, the decrease in traffic is due to the fact that through traffic for Laconia and points north begins to divert here over South Pembroke road past Concord Airport as a short cut to route 106, avoiding the main street of Concord.

It is stated in the earlier report[3] that "It is not expected that the estimates of traffic in 1931 and in 1936 will in all cases reflect the actual traffic on each section of highway in these years, but it is believed that the estimates will reflect with reasonable accuracy ighw traffic on the trunk-line system."

Although the 1931 results have come well within the statement of expected results as above quoted, it is probable that closer estimates might have been made had gasoline consumption data for New Hampshire been available in 1926. Study of this data indicates a much closer relationship between gasoline consumption and traffic volume than between registration and traffic volume[4] particularly for the years subsequent to 1924 or 1925. The year 1924 is the first for which statistics of gasoline consumption were available for New Hampshire. When the 1926 traffic forecast was made, the gasoline consumption series for New Hampshire, as in most States, was but two years in length, too short a period to use it for forecasting purposes. The increase of 1931 traffic over 1926 traffic is 75 per cent. Gasoline consumption figures for 1931 indicate an increase over 1926 consumption in New Hampshire amounting to 73 per cent.

Special attention was paid to the occurrence of solid-tired trucks in the 1931 survey. It was found that such trucks amounted to six-tenths of 1 per cent of all trucks observed upon the highway.

A tabulation of traffic by types of vehicle for each station is given in Table 3.

[3] Report of a Survey of Transportation on the State Highways of New Hampshire, 1927, p. 57.

[4] Report of a Survey of Traffic on the Federal-aid Highway Systems of 11 Western States, 1930.

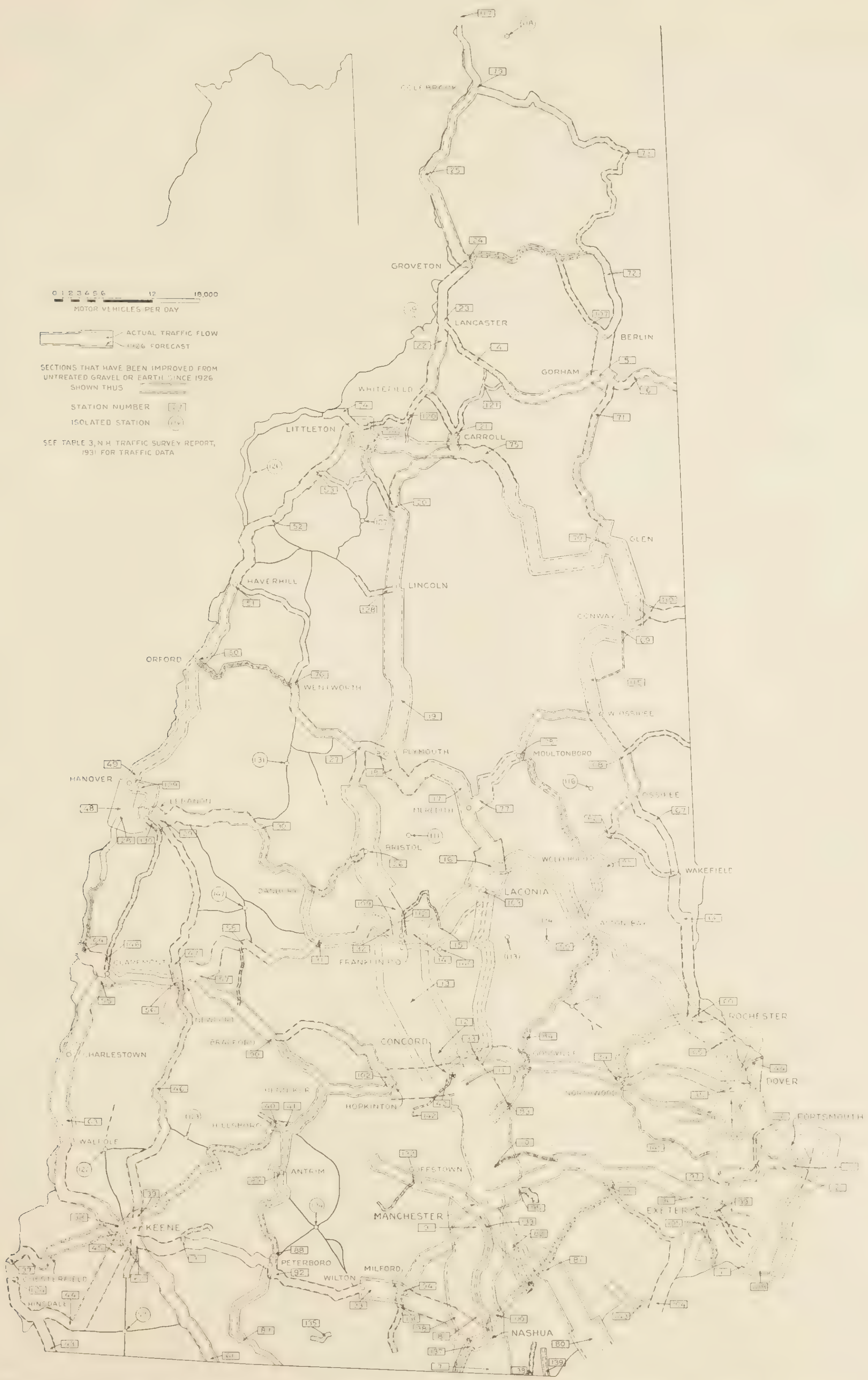

Figure 1.—Average Daily Motor Vehicle Traffic on New Hampshire Roads and Comparison with 1926 Forecast. Locations of Traffic Survey Stations Are Also Shown

TABLE 3.—*Comparison of motor vehicle traffic at New Hampshire traffic survey stations in 1931 with forecast for 1931 based on survey in 1926* [1]

Station No.[2]	Direction from station	Route No.[3]	Trucks, 1931	Passenger cars, 1931	Total vehicles, 1931	Total vehicles forecast, 1926
1	N	U. S. 1	678	10,352	11,030	9,370
	S	U. S. 1	445	8,272	8,717	8,190
	W	Mass. 110	107	1,795	1,902	1,270
2	N	U. S. 1	366	5,949	6,315	8,890
	S	U. S. 1	335	5,914	6,249	8,880
	E	T. R.	45	80	125	80
	W	T. R.	34	112	146	80
3	N	1-A	81	4,281	4,362	4,670
	S	T. R.	30	376	406	1,910
	E	1-A	214	3,995	4,109	2,860
4	N	T. R.	16	96	112	80
	E	U. S. 2	90	705	795	730
	W	U. S. 2	85	706	791	700
5	N	16	169	1,854	2,023	2,240
	S	U. S. 2	207	2,632	2,839	2,510
	W	U. S. 2	77	1,218	1,295	980
6	N	S. A.	21	109	130	110
	E	U. S. 2	82	972	1,054	760
	W	U. S. 2	65	1,030	1,095	830
7	N	U. S. 3	497	6,504	7,001	6,540
	S	U. S. 3	499	6,504	7,003	6,540
	W	T. R.	(4)	3	3	----------
8	N	U. S. 3	442	5,528	5,970	5,300
	S	U. S. 3	442	5,528	5,970	5,300
9	N	U. S. 3	487	6,196	6,683	6,000
	S	U. S. 3	479	6,048	6,527	5,910
	W	T. R.	36	232	268	160
10	N	U. S. 3	609	5,495	6,104	5,580
	S	U. S. 3	548	5,661	6,209	5,690
	E	101-B	51	240	291	110
11	N	T. R.	89	995	1,084	----------
	S	U. S. 3	422	5,356	5,778	6,810
	W	U. S. 3	374	4,722	5,096	6,810
12	N	U. S. 3	343	4,442	4,785	6,560
	S	U. S. 3	348	3,991	4,339	6,560
13	N	U. S. 3	230	1,907	2,137	3,860
	S	U. S. 3	278	2,238	2,516	4,180
	W	S. A.	42	531	573	350
14	N	T. R.	10	76	86	180
	E	U. S. 3	163	2,001	2,164	3,650
	W	U. S. 3	199	2,008	2,207	3,740
15	N	U. S. 3	257	2,053	2,310	3,120
	S	U. S. 3	212	2,105	2,317	3,270
	W	S. A.	52	197	249	230
16	N	U. S. 3	260	3,199	3,459	3,530
	S	U. S. 3	374	4,265	4,639	4,020
	E	11	152	1,557	1,709	1,100
17	N	U. S. 3	91	2,051	2,142	1,560
	S	U. S. 3	86	1,932	2,018	1,540
	E	S. A.	29	426	455	310
18	N	U. S. 3	199	1,747	1,946	1,770
	S	U. S. 3	198	1,670	1,868	1,720
	W	T. R.	9	45	54	70
19	N	U. S. 3	67	2,510	2,577	2,140
	S	U. S. 3	110	2,531	2,641	2,160
	E	S. A.	78	185	263	220
20	N	105	31	740	771	700
	S	U. S. 3	46	1,890	1,936	1,620
	E	U. S. 3	19	1,314	1,333	1,030
21	N	115	40	628	668	490
	S	U. S. 3	76	1,323	1,399	1,150
	W	U. S. 3	54	842	896	800
22	N	U. S. 3	92	1,461	1,553	1,230
	S	U. S. 3	78	1,375	1,453	1,220
	W	T. R.	18	154	172	20
23	N	U. S. 3	116	1,118	1,234	1,300
	S	U. S. 3	119	1,147	1,266	1,300
	E	T. R.	8	60	68	20
24	N	U. S. 3	166	1,465	1,631	1,350
	S	S. A.	25	177	202	80
	E	S. A.	86	563	659	230
	W	U. S. 3	92	1,090	1,182	1,190
25	N	U. S. 3	96	999	1,095	660
	S	U. S. 3	94	1,152	1,246	730
	W	T. R.	95	714	809	310
26	N	3-A	305	2,791	3,096	2,220
	S	3-A	334	3,053	3,387	2,389
	W	4-B	81	696	777	480
27	S	3-A	65	1,077	1,142	1,030
	E	25	90	1,277	1,367	1,370
	W	25	98	1,134	1,232	790
28	S	T. R.	145	570	715	340
	E	4	374	2,769	3,143	2,280
	W	4	409	3,199	3,608	2,510
28	N	"A" D. C.[5]	248	2,269	2,517	----------
	S	S. A.	145	570	715	340
	E	D. C.[5]	374	2,769	3,143	2,280
	W	"B" D. C.[5]	409	3,199	3,608	2,510
29	S	10	57	856	913	810
	E	U. S. 4	154	1,465	1,619	1,410
	W	U. S. 4	202	2,149	2,351	2,110
30	N	U. S. 4	52	793	845	530
	S	U. S. 4	52	793	845	530
31	N	U. S. 4	100	991	1,091	390
	E	U. S. 4 and 11	148	1,559	1,707	1,080
	W	11	104	1,006	1,110	830
32	E	11	113	1,221	1,334	1,970
	W	11	114	1,317	1,441	1,970
	S	Old 11	24	154	178	----------
33	N	106	99	1,454	1,553	480
	E	9	112	1,732	1,844	1,570
	W	9	200	3,054	3,254	2,100
34	S	4-A	75	705	780	300
	E	9	83	881	964	700
	W	9	103	1,254	1,357	920
35	S	T. R.	97	445	552	370
	E	9	258	1,661	1,919	1,620
	W	9	133	1,221	1,354	1,360
36	N	U. S. 4	207	2,830	3,037	2,690
	S	U. S. 4	198	2,626	2,824	2,450
	W	S. A.	23	360	383	280
37	N	9	49	966	1,015	850
	E	T. R.	6	37	43	30
	W	9	51	997	1,048	960
38	N	12	180	1,949	2,129	1,380
	E	9 and 12	268	3,277	3,545	2,370
	W	9	101	1,489	1,590	960
39	N	10	88	878	966	1,230
	S	9 and 10	162	1,910	2,072	1,880
	E	9	83	1,089	1,172	690
40	N	S. A.	50	524	574	570
	E	9	76	1,208	1,284	1,060
	W	9	35	764	799	490
41	N	9 and 32	95	1,211	1,306	850
	S	9 and 32	109	1,268	1,377	920
	W	T. R.	16	65	81	100
42	S	S. A.	104	792	896	----------
	E	9 and 103	252	4,091	4,343	3,790
	W	9 and 103	229	3,451	3,680	3,790
43	N. and S.	10	50	1,173	1,223	1,420
44	E. and W.	10	96	1,084	1,180	1,230
45	N	10 and D. C.[5]	154	1,733	1,887	2,120
	S	10 and D. C.[5]	154	1,736	1,890	2,120
	W	T. R.	8	52	60	50
46	N	10	34	535	569	830
	S	10 and 101	39	562	601	920
	W	101	15	103	118	190
47	N	10	88	883	971	1,010
	S	10	105	1,053	1,158	1,200
	W	T. R.	34	207	241	210
48	N	10	226	2,324	2,550	1,650
	S	10	570	3,087	3,657	1,650
49	N	10	149	1,614	1,763	1,020
	S	10	192	1,655	1,847	1,060
	E	T. R.	33	82	115	60
50	N	10 and D. C.[5]	133	1,583	1,716	970
	S	10 and D. C.[5]	108	1,428	1,536	870
	E	111	74	476	550	190
51	N	10 and 25	129	1,333	1,462	1,290
	S	10	105	1,081	1,186	880
	E	25	53	609	662	580
52	N	10	94	996	1,090	1,090
	S	S. A.	41	192	233	180
	W	10	93	1,068	1,161	1,110
53	N	10	134	1,086	1,220	970
	S	10	141	1,403	1,544	1,380
	E	117	46	466	512	510
54	S	105	71	1,015	1,086	710
	E	10 and 18	113	1,943	2,056	1,500
	W	10 and 18	171	2,478	2,649	2,020
55	N	11 and 12	236	2,549	2,785	2,490
	S	11 and 12	154	1,436	1,590	1,280
	W	T. R.	91	1,158	1,249	1,310
56	S	S. A.	130	1,427	1,557	320
	E	11	198	2,259	2,457	2,070
	W	11	70	841	911	1,770
57	N	11	118	1,537	1,655	1,930
	S	32 and 103	131	1,228	1,359	990
	W	11 and 103	159	2,135	2,294	2,040
58	S	103-A	26	308	334	180
	E	11	58	1,005	1,063	910
	W	11	74	1,074	1,148	1,090
59	N	11 and 28	142	2,327	2,469	1,160
	S	28	57	610	667	330
	E	11	108	1,707	1,815	1,030
60	N	11	322	2,671	2,993	1,900
	S	T. R.	188	695	883	460
	E	104 and 11	489	4,116	4,605	2,830
	W	104	191	1,052	1,243	530
61	N	12	89	1,422	1,511	1,190
	S	12	90	1,450	1,540	1,200
	E	T. R.	4	46	50	10
62	N	12	358	2,466	2,824	2,110
	S	12	210	1,684	1,894	1,470
	W	T. R.	157	733	890	810
63	N	12 and 101	146	1,762	1,908	2,600
	S	12	78	1,140	1,218	2,110
	E	101	71	648	719	570
64	N	T. R.	33	145	178	470
	S	12	198	1,544	1,742	1,730
	W	12	171	1,394	1,565	1,180
65	N	16	363	2,937	3,300	3,230
	S	16-A	266	2,413	2,679	190
	E	16	136	668	804	3,060
	W	T. R.	8	18	26	20
66	N	16	102	1,271	1,373	1,370
	S	16	94	1,380	1,474	1,350
	E	S. A.	40	259	299	360

[1] Average daily traffic for the period from July 17, to Oct. 16.
[2] For locations of stations see fig. 1.
[3] The United States routes are designated by the initials U. S., State routes by number only, State-aid roads by S. A., and township roads by T. R.
[4] Less than 1 per day.
[5] Local designation.

TABLE 3.—*Comparison of motor vehicle traffic at New Hampshire traffic survey stations in 1931 with forecast for 1931 based on survey in 1926*—Continued

Station No	Direction from station	Route No.	Trucks, 1931	Passenger cars, 1931	Total vehicles, 1931	Total vehicles forecast, 1926
67	N	16	44	998	1,042	930
	S	16	46	841	887	920
	E	T. R	8	60	68	30
	W	T. R	1	8	9	----------
68	N	16 and 25	98	1,297	1,395	1,160
	S	16 and 28	100	1,345	1,445	1,220
	E	25	78	565	643	520
69	N	16 and 28	70	1,901	1,971	1,340
	S	16 and 28	69	1,764	1,833	1,230
	E	T. R	14	207	221	150
70	N	16	59	1,744	1,803	1,330
	E	16	80	2,562	2,642	2,060
	W	18	82	1,900	1,982	1,440
71	N	16	33	878	911	730
	S	16	37	910	947	700
	W	T. R	13	150	163	90
72	N	16	107	840	947	910
	S	16	106	837	943	1,030
	E	T. R	30	67	97	150
	W	T. R	29	96	125	150
73	S	16	39	555	594	530
	E	26	44	608	652	440
	W	26	34	701	735	620
74	N	T. R	6	49	55	10
	E	18	101	881	982	1,010
	W	18	88	980	1,068	1,020
75	E. and W	18	52	1,604	1,656	1,820
76	N	25	68	675	743	720
	S	25	96	864	960	800
	W	111	50	365	415	130
77	N	T. R	2	32	34	40
	S	25	170	1,667	1,837	1,620
	E	25	168	1,647	1,815	1,590
78	N	25	35	960	995	710
	S	25	83	1,460	1,543	760
	E	107	52	722	774	340
79	E. and W	26	118	818	936	950
80	N	28	355	4,030	4,385	3,590
	S	28	275	4,028	4,303	3,600
	E	T. R	22	82	104	90
	W	T. R	80	178	258	100
81	N	28	258	2,484	2,742	3,070
	S	T. R	63	325	388	100
	E	28	262	2,201	2,463	3,020
	W	T. R	18	59	77	80
82	N	28	243	1,669	1,912	2,950
	S [6]	S. A	174	1,096	1,270	300
	E [6]	28	107	409	516	2,680
83	N	28	105	1,151	1,256	840
	S	28	102	1,138	1,240	830
	W	T. R	9	63	72	40
85	N	28	74	1,275	1,349	480
	S	T. R	22	151	173	110
	W	28	70	1,171	1,241	390
86	N	28	61	748	809	680
	S	28	90	1,187	1,277	950
	E	S. A	62	582	644	560
	W	T. R	10	44	54	20
87	N	32	77	1,107	1,184	620
	S	32	47	653	700	610
	E	32 (old)	40	625	665	10
88	N	32	85	620	705	390
	S	32	100	887	987	710
	E	T. R	43	359	402	390
89	N	32	70	673	743	400
	S	32	156	1,338	1,494	750
	W	3-A	92	728	820	390
90	N	S. A	25	330	355	----------
	S	32	64	1,102	1,166	500
	E	103	63	730	793	890
	W	32 and 103	103	1,684	1,787	1,390
91	N	S. A	33	358	391	440
	E	101	70	1,156	1,226	1,220
	W	101	92	1,419	1,511	1,590
92	N	T. R	7	48	55	80
	S	T. R	29	144	173	170
	E	101	105	966	1,071	1,010
	W	101	123	1,076	1,199	1,130
93	E. and W	101	271	2,446	2,717	1,990
94	N	101	174	1,435	1,609	1,190
	S	101	203	1,533	1,736	1,250
	E	T. R	28	98	126	120
95	N	T. R	6	18	24	30
	S	S. A	91	636	727	640
	E	101	167	1,514	1,681	2,160
	W	101	241	2,071	2,312	2,720
96	N	T. R	2	16	18	10
	E	101	87	2,036	2,113	1,630
	W	101	85	2,016	2,101	1,630
97	N	108	157	1,391	1,548	920
	S	101 and 108	207	2,267	2,474	1,590
	E	101	142	1,366	1,508	1,110
98	N	T. R	14	80	94	70
	S	T. R	3	23	26	10
	E	101-A	267	1,917	2,184	2,470
	W	101-A	263	1,935	2,198	2,430
99	S	S. A	46	565	611	460
	E	101-C	94	1,505	1,599	1,840
	W	101-C	136	2,043	2,179	2,270

Station No.	Direction from station	Route No.	Trucks, 1931	Passenger cars, 1931	Total vehicles, 1931	Total vehicles forecast, 1926
100	S	T. R	5	23	28	10
	E	102	124	804	928	470
	W	102	124	804	928	470
101	N	109	86	945	1,031	590
	E	109	64	551	615	490
	W	102	27	441	468	120
102	N. and S	103	86	948	1,034	1,310
103	N	106	205	2,365	2,570	720
	S	106	132	1,949	2,081	450
	E	T. R	91	515	606	370
104	N. and S	108	113	1,769	1,882	1,850
105	N	108	122	1,746	1,868	1,010
	S	108	77	1,205	1,282	740
	E	S. A	47	584	631	280
106	N	108	182	3,051	3,233	2,760
	S	108	178	2,904	3,082	2,680
	E	T. R	12	115	127	70
	W	T. R	4	47	51	50
107	E	110	132	561	693	600
	W	110	133	591	724	600
108	N	1-A	116	2,288	2,404	3,630
	S	1-A	116	2,290	2,406	3,550
	W	T. R	57	737	794	480
109	N. and S	3-A	134	1,560	1,694	1,650
110	N	18	51	905	956	1,260
	E	18 and 28	81	1,316	1,397	1,510
	W	T. R	43	630	673	600
111	N	S. A	51	416	467	240
	S	S. A	57	478	535	290
	W	T. R	23	153	176	60
112	N. and S	S. A	41	328	369	240
113	N	T. R	8	93	101	140
	S	T. R	17	170	187	110
	E	T. R	19	124	143	60
	W	T. R	16	160	176	100
	NW	T. R	22	176	198	70
115	N	T. R	35	160	195	80
	E	S. A	40	245	285	190
	W	T. R	15	113	128	110
116	N	T. R	5	46	51	20
	S	T. R	3	31	34	30
	E	T. R	7	60	67	60
	W	S. A	6	56	62	60
117	N	S. A	50	601	651	180
	S	S. A	50	561	611	----------
	E	S. A	33	159	192	130
	W	S. A	17	65	82	80
118	N	S. A	17	46	63	50
	S	S. A	15	51	66	80
	W	S. A	7	8	15	10
119	N	S. A	47	117	164	140
	S	S. A	47	120	167	140
	E	T. R	2	14	16	10
120	N	116	60	725	785	580
	S	T. R	24	285	309	250
	W	116	45	484	529	380
121	N	T. R	27	241	268	210
	S	115	36	450	486	410
	E	115	32	339	371	250
122	N	T. R	8	42	50	80
	S	S. A	9	57	66	120
	E	T. R	5	36	41	60
123	N	T. R	(4)	4	4	10
	E	T. R	9	71	80	100
	W	T. R	9	69	78	90
125	N	T. R	7	111	118	160
	S	S. A	7	79	86	90
	E	S. A	10	150	160	170
	W	S. A	11	135	146	120
126	N	T. R	7	34	41	40
	S	T. R	5	34	39	40
	E	T. R	2	5	7	----------
127	N	S. A	5	40	45	30
	S	112	15	131	146	120
	E	112	17	130	147	110
128	E. and W	112	34	540	574	610
129	S	T. R	57	201	258	280
	E	S. A	150	1,410	1,560	1,120
	W	S. A	193	1,583	1,776	1,280
130	N	10-A	71	531	602	570
	S	10-A	67	505	572	540
	W	T. R	12	61	73	60
131	N	S. A	14	49	63	50
	S	S. A	12	50	62	60
	E	T. R	8	14	22	----------
132	N	T. R	32	132	164	110
	S	T. R	48	263	311	220
	E	114	166	1,602	1,768	1,190
	W	114	141	1,358	1,499	1,020
133	N. and S	S. A	81	930	1,011	200
134	N	T. R	29	451	480	250
	S	S. A	70	689	759	370
	E	T. R	25	238	263	140
	W	S. A	38	310	348	270
	SW	T. R	38	383	421	30
135	E. and W	S. A	77	417	494	480
136	N	S. A	107	719	826	590
	S	S. A	77	622	699	490
	E	T. R	40	139	179	140

[4] Less than 1 per day.
[6] Route 28 under construction for a distance of 3.7 miles during 1931 survey. Traffic was detoured south over State-aid route to route 102 during this time.

TABLE 3.—*Comparison of motor vehicle traffic at New Hampshire traffic survey stations in 1931 with forecast for 1931 based on survey in 1926*—Continued

Station No.	Direction from station	Route No.	Trucks, 1931	Passenger cars, 1931	Total vehicles, 1931	Total vehicles forecast, 1926
137	S	S. A	103	700	803	950
	E	S. A	262	1,647	1,909	1,210
	W	T. R	161	1,016	1,177	630
138	N	S. A	59	346	405	490
	S	S. A	60	350	410	490
	W	T. R	7	41	48	40
139	N. and S.	S. A	64	650	714	370
140	N	S. A	55	462	517	430
	S	S. A	47	425	472	350
	E	T. R	11	58	69	80
	W	T. R	2	14	16	20
141	N. and S.	S. A	20	118	138	210
142	N	S. A	33	200	233	210
	S	S. A	29	159	188	150
	W	T. R	8	51	59	60
143	N	S. A	167	1,747	1,914	1,500
	E	S. A	84	1,064	1,148	2,670
	W	S. A	98	765	863	1,230
144	N	T. R	147	1,239	1,386	1,230
	S	T. R	23	191	214	70
	E	T. R	33	271	304	230
	W	S. A	78	722	800	510
	SW	T. R	87	873	960	970
145	N	T. R	16	158	174	200
	S	T. R	20	169	189	200
	E	T. R	21	180	201	250
	W	T. R	22	165	187	220
146	N	10-A	63	343	406	530
	S	10-A	64	340	404	540
	E	T. R	4	11	15	20
	W	T. R	7	16	23	------
147	N	T. R	13	64	77	80
	S	T. R	1	12	13	20
	E	T. R	12	72	84	110
	W	T. R	23	128	15	190

(Continued from p. 130)

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CEMENT CONCRETE GIVES GOOD SERVICE ON CONNECTICUT AVENUE EXPERIMENTAL ROAD

Three sections of the Connecticut Avenue experimental road (experiments 3, 4, and 5, north of Bradley Lane) were built of Portland cement concrete. A portion of the work was done in the fall of 1912, and the sections were completed in May, 1913. The photographs shown on the covers of this issue were taken on experiment 5. The back cover shows the method used in construction and the appearance of the pavement about a year after completion. The front cover shows the appearance of a typical section in August, 1932.

The concrete on experiment 5 was composed of a 1:1¾:3 mix. Gravel, limestone, and trap rock were used as coarse aggregate in different sections of the experiment. The thickness of the pavement is 6 inches throughout. The cost of the surface was 142.29 cents per square yard. In 1922 this experimental section was surface-treated with a hot application of 0.26 gallon of refined coal tar and pea gravel. This mat surface has now entirely disappeared.

The subgrade on which the Connecticut Avenue experimental road was constructed is a silty loam with varying percentages of mica. Excessive mica causes detrimental elasticity in soils, and this fact may account in part for the large amount of cracking which has occurred in the concrete sections.

It is also believed that defective drainage has had a great deal to do with the deterioration of the concrete. In February, 1929 (see PUBLIC ROADS, vol. 11, No. 4, June, 1930), immediately after a heavy rain, it was noted that a considerable volume of water was flowing to the surface of the concrete sections through the cracks. This condition was found throughout the concrete portion of the experiment, although it was most severe on experiment 3. It was also observed that the sewers were not receiving any flow from either side drain or through the cross drains. Upon digging down into the French drains it was found that wherever one of the utility companies had made a cut through the drain line, it had failed to replace either tile or stone and had backfilled the trench with earth, thereby effectively destroying the drainage system. It was learned from the records of the sanitary commission that most of the service connections were made in 1922. It is also a fact that the cost of maintaining the concrete sections has materially increased since that year. The total cost of maintenance to date, including the surface treatment in 1922, amounts to 37.71 cents per square yard.

The concrete portion of the Connecticut Avenue experimental road can not be regarded as a particularly successful example of concrete road construction even for the early day in which it was built; and great advances have been made, in both knowledge and technique, since that time. However, in spite of the excessive cracking in some areas, the pavement is still in service under an average traffic of about 3,000 vehicles per day.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

CURRENT STATUS OF FEDERAL-AID ROAD CONSTRUCTION

AS OF

SEPTEMBER 30, 1932

STATE	COMPLETED MILEAGE	UNDER CONSTRUCTION						APPROVED FOR CONSTRUCTION					BALANCE OF FEDERAL-AID FUNDS AVAILABLE FOR NEW PROJECTS	STATE
		Estimated total cost	Federal-aid allotted	Percentage completed	MILEAGE Initial	MILEAGE Stage[1]	MILEAGE Total	Estimated total cost	Federal-aid allotted	MILEAGE Initial	MILEAGE Stage[1]	MILEAGE Total		
Alabama	2,418.7	$ 1,257,811.92	$ 607,009.92	99	49.3		49.3	$ 2,170,626.64	$ 1,085,313.26	63.4	33.0	96.4	$ 4,385,699.70	Alabama
Arizona	1,254.6	2,700,914.60	1,631,424.04	64	65.8	97.4	163.2	583,308.09	123,802.52	30.1	30.6	60.7	231,407.42	Arizona
Arkansas	1,967.2	2,262,708.94	1,033,985.95	85	64.5	38.4	102.9	362,032.53	181,016.26	17.3		17.3	2,183,603.25	Arkansas
California	2,410.4	7,547,903.09	3,594,088.12	67	176.6	39.3	215.9	985,578.29	60,131.16	12.7	7.6	20.3	459,301.63	California
Colorado	1,615.4	3,839,201.88	2,031,886.03	89	148.8	68.6	217.4						1,788,004.65	Colorado
Connecticut	287.0	4,071,872.74	1,479,495.06	77	24.9		24.9	938,125.66	441,086.28	15.1		15.1	225,940.18	Connecticut
Delaware	367.9	797,087.35	358,463.00	90	22.1	2.0	24.1	13,166.40	2,500.00	.2	.1	.3	139,440.82	Delaware
Florida	660.2	3,668,655.29	1,696,567.65	72	105.0		105.0	88,745.83	44,372.91	4.7		4.7	2,505,435.86	Florida
Georgia	3,159.4	5,742,147.73	2,593,600.14	73	123.1	147.5	270.6	566,378.33	241,004.44	25.2	3.9	29.1	781,344.34	Georgia
Idaho	1,260.2	3,200,934.38	1,879,704.51	84	134.4	315.7	450.1	665,214.83	170,816.10	39.6	48.4	88.0	304,388.69	Idaho
Illinois	2,777.7	24,390,834.30	11,220,790.34	86	738.0	37.5	775.5	4,110,799.43	953,338.61	115.2	5.2	120.4	715,060.85	Illinois
Indiana	1,883.2	10,060,334.77	4,997,511.19	83	376.2	15.9	392.1	316,400.18	158,198.94	16.0		16.0	339,387.72	Indiana
Iowa	3,297.5	7,946,729.37	2,667,207.51	76	384.6	89.9	474.5	1,220,311.26	22,923.25	50.5	1.2	51.7	9,944.78	Iowa
Kansas	3,549.4	5,041,360.98	2,458,180.14	69	240.2	237.3	477.5	2,321,436.18	664,103.29	158.3	53.6	211.9	304,715.61	Kansas
Kentucky	1,820.5	3,596,756.19	1,418,380.52	61	161.9	108.6	270.5	1,896,177.98	637,787.66	76.7	60.2	136.9	468,144.52	Kentucky
Louisiana	1,569.2	7,109,560.16	3,296,068.98	52	86.1	9.9	96.0	1,083,662.52	278,102.31	27.4	4.5	31.9	513,742.69	Louisiana
Maine	748.7	2,629,773.58	1,136,825.80	84	89.2		89.2	495,904.06	111,099.78	23.1		23.1	104,340.95	Maine
Maryland	794.5	1,729,540.73	754,093.93	57	66.3	4.6	70.9	145,106.45	51,453.72	5.4	1.5	6.9	27,400.49	Maryland
Massachusetts	821.6	6,819,080.31	2,588,009.96	85	72.3	6.6	78.9	1,076,511.01	264,318.57	13.4	2.1	15.5	130,743.13	Massachusetts
Michigan	2,156.2	8,285,935.23	3,618,443.29	73	311.5	75.8	387.3	1,501,894.90	521,455.00	61.3	15.2	76.5	1,031,277.36	Michigan
Minnesota	3,849.9	14,620,610.63	3,960,301.38	93	267.9	403.0	670.9	1,521,934.97	10,600.00	69.0	32.4	101.4	8,400.00	Minnesota
Mississippi	1,818.2	3,952,195.21	1,936,470.53	83	201.8	73.1	274.9	135,336.30	67,668.14	4.4	.2	4.6	4,924,347.04	Mississippi
Missouri	3,033.6	5,008,894.87	2,116,809.03	76	124.8	61.2	186.0	1,160,882.81	243,619.71	68.0	5.0	73.0	459,932.21	Missouri
Montana	2,727.3	4,508,846.58	2,541,932.75	75	399.9	105.4	505.3	1,763,307.02	939,824.58	97.6	177.2	274.8	1,758,180.06	Montana
Nebraska	4,220.8	3,446,743.26	1,676,726.38	58	121.7	116.3	238.0	1,188,761.70	561,820.82	31.4	38.8	70.2	1,508,591.11	Nebraska
Nevada	1,328.6	1,963,828.00	1,647,258.61	78	38.4	125.2	163.6	175,911.80	70,528.72		35.2	35.2	71,286.33	Nevada
New Hampshire	425.4	695,726.79	318,698.36	43	23.3	2.8	26.1	29,252.65	11,701.06	1.5		1.5	277,434.90	New Hampshire
New Jersey	623.6	6,285,477.62	2,329,616.22	52	38.9	.5	39.4	1,212,488.84	303,122.19	23.0		23.0	117,276.97	New Jersey
New Mexico	2,222.1	2,004,098.43	1,354,606.04	80	84.9	45.9	130.8	1,033,921.62	426,786.90	50.3	49.7	100.0	727,640.42	New Mexico
New York	3,280.8	19,581,650.00	8,133,273.00	60	539.1	17.7	556.8	6,145,800.00	1,030,125.00	104.0	11.4	115.4	1,222,104.60	New York
North Carolina	2,222.4	1,916,337.19	955,341.85	58	151.9	9.0	160.9	1,428,485.12	719,502.07	191.9	17.2	209.1	2,771,461.76	North Carolina
North Dakota	4,951.7	4,540,483.91	2,056,995.48	66	510.8	487.3	998.1	1,766,172.72	814,176.63	74.3	301.7	376.0	208,600.79	North Dakota
Ohio	2,857.3	11,546,103.40	3,822,167.43	64	274.7	91.2	365.9	1,202,537.00	265,168.52	24.9	10.9	35.8	809,740.59	Ohio
Oklahoma	2,333.5	4,037,930.62	1,983,608.83	75	212.1	43.5	255.6	1,044,113.36	563,526.09	47.5	10.8	58.3	874,482.27	Oklahoma
Oregon	1,515.4	3,527,380.58	1,885,614.10	77	130.9	96.5	227.4	607,931.83	198,214.33	20.4	44.9	65.3	730,581.32	Oregon
Pennsylvania	3,052.4	10,113,662.29	4,555,059.33	60	331.0		331.0	2,379,893.71	703,488.85	71.3		71.3	965,356.01	Pennsylvania
Rhode Island	258.2	1,170,799.67	357,950.47	70	20.7	4.3	25.0						260,037.51	Rhode Island
South Carolina	2,043.9	2,656,702.92	1,162,269.32	91	60.6	46.8	107.4	1,374,216.08	465,354.00	124.3	54.0	178.3	184,493.25	South Carolina
South Dakota	3,923.1	5,366,921.59	2,588,066.63	60	424.3	311.2	735.5	116,382.69	51,770.14	21.4	9.9	31.3	152,258.70	South Dakota
Tennessee	1,693.1	2,016,384.60	1,004,738.14	46	68.5	21.8	90.3	2,042,411.29	1,021,205.58	84.9	7.5	92.4	1,814,549.10	Tennessee
Texas	7,809.5	14,568,472.31	6,519,508.53	70	727.0	292.0	1,019.0	4,789,118.58	1,782,682.61	186.6	223.6	410.2	1,798,044.54	Texas
Utah	1,123.5	1,578,866.18	1,117,471.68	74	95.5	134.6	230.1	768,585.66	208,748.74	46.8	5.1	51.9	415,392.45	Utah
Vermont	352.5	819,001.36	386,890.83	68	32.3		32.3	80,521.43	7,246.93	7.0		7.0	46,423.32	Vermont
Virginia	1,917.9	2,534,859.55	1,230,847.77	67	143.8	23.3	167.1	1,208,197.34	533,445.09	58.2	7.9	66.1	1,204,351.54	Virginia
Washington	1,236.3	2,790,083.63	1,275,720.63	87	97.3	7.4	104.7	1,054,412.78	262,423.12	38.7	1.1	39.8	572,278.77	Washington
West Virginia	899.8	2,304,566.52	897,622.54	76	61.4	5.0	66.4	1,894,163.38	620,267.41	69.9	8.1	78.0	315,328.26	West Virginia
Wisconsin	2,559.3	9,805,172.92	3,586,122.02	87	263.8	114.8	378.6	790,708.51	88,000.00	25.2	25.6	50.8	151,382.52	Wisconsin
Wyoming	1,950.0	3,439,473.97	2,144,615.04	88	187.6	215.1	402.7	211,017.21	86,284.57	25.4	5.4	30.8	25,683.05	Wyoming
Hawaii	74.8	1,442,767.53	920,136.34	43	40.6	1.7	42.3	651,487.23	324,288.62	15.3	1.9	17.2	1,050,166.62	Hawaii
TOTALS	101,124.4	260,943,185.67	115,528,175.34	73	9,116.3	4,151.6	13,267.9	58,319,334.20	18,394,414.48	2,338.8	1,352.6	3,691.4	42,075,130.65	TOTALS
Construction completed		183,569,000.00	84,645,000.00											
Balance uncompleted		77,374,000.00	30,883,000.00											

[1] The term stage construction refers to additional work done on projects previously improved with Federal-aid. In general, such additional work consists of the construction of a surface of higher type than was provided in the initial improvement.

CONCRETE CONSTRUCTION ON CONNECTICUT AVENUE EXPERIMENTAL ROAD, NOVEMBER, 1912

CONDITION OF CONCRETE SURFACE IN APRIL, 1914

U. S. GOVERNMENT PRINTING OFFICE: 1932